Sensor & Model Enabled Water Quality & Security Assessment System For Situational Awareness Of Water Distribution Networks

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US Army Corps of Engineers
BUILDING STRONG®

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ASCE 2009 Report Card For America's Infrastructure

- Drinking Water : D-

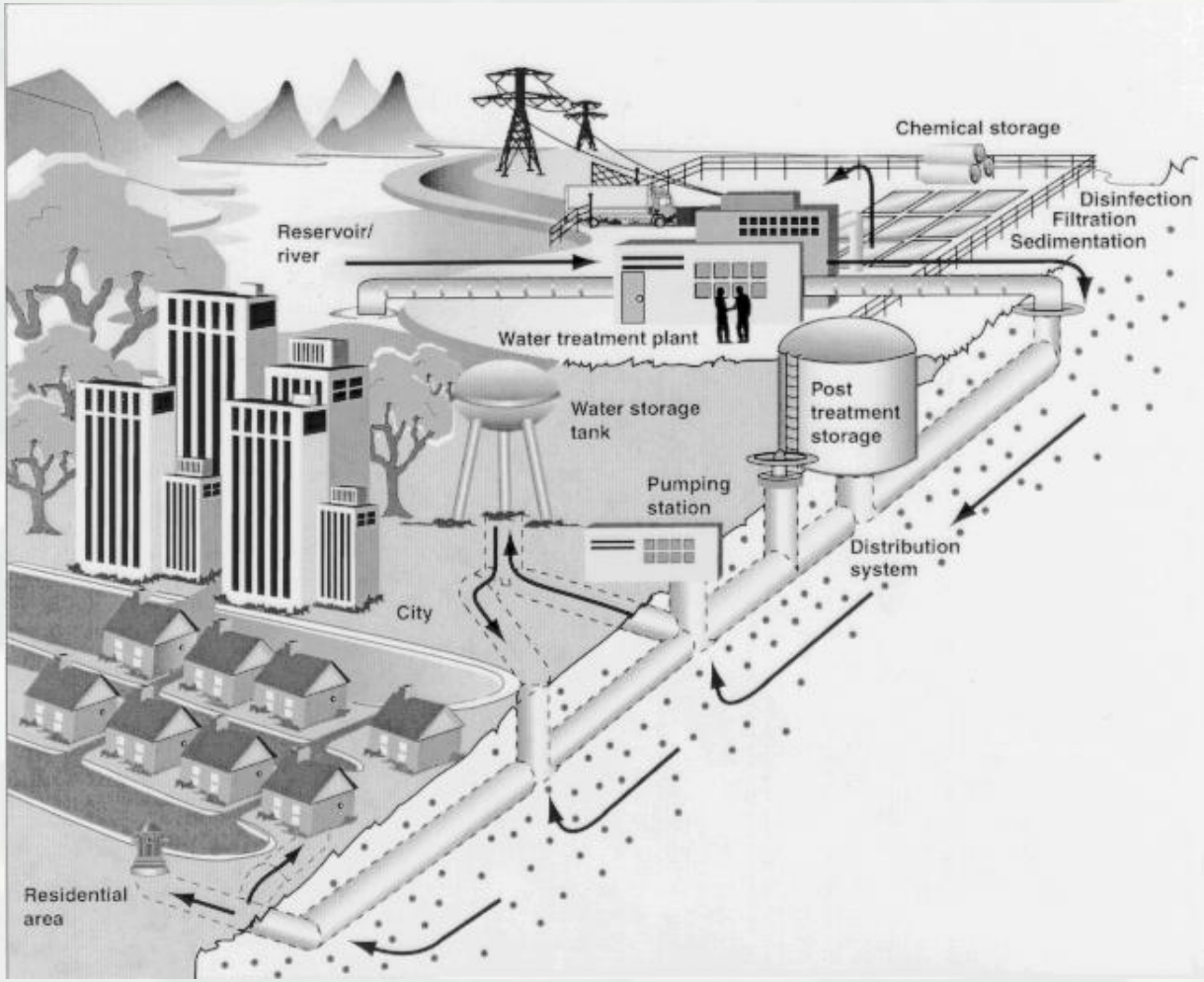
Tuberculation in 6-inch Unlined CI Water Main

Extent And Magnitude Of The Problem

- Potable Water Distribution System: 880,000 miles of pipe comprise the nation's drinking water distribution network [AWWA WATER\STATS2002].
- A Department of Defense report estimates that corrosion related problems cost the Department of Defense $15 billion dollars/year.

  - Source: (REPORT SKT50T2, MAY 2007): The Annual Cost of Corrosion for the DOD Facilities and Infrastructure)

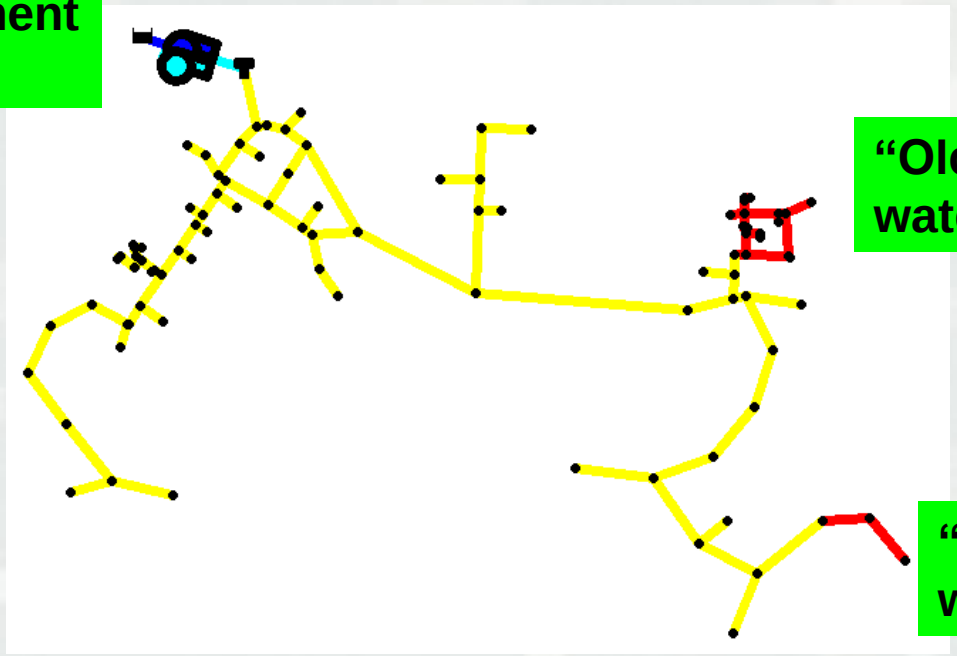
Typical Water Distribution Systems



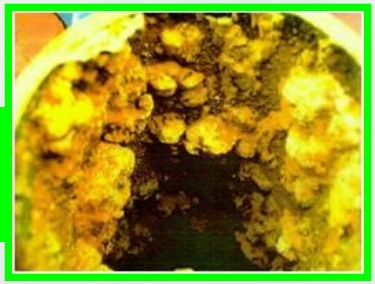
- Potential corrosion problems
- Threat to Water Potability
- Threat to Fire Suppression
- Lack of system redundancy
- Large area subtended by the system
- Treatment chemicals
- Control systems (SCADA)

Degradation Of Water Quality In The Distribution System Can Result In Undetected Localized Corrosion Problems

Treatment plant



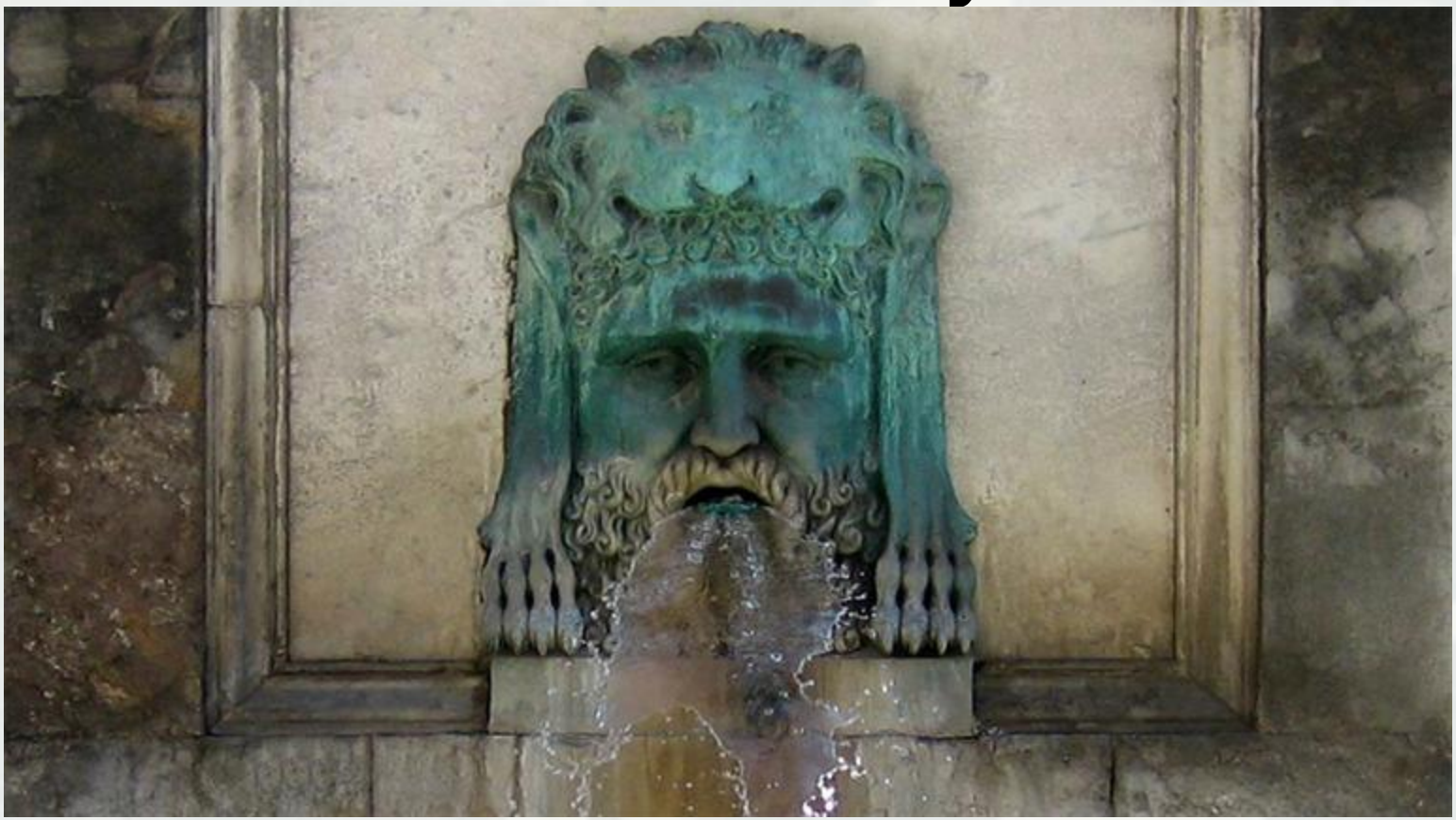
"Old" water



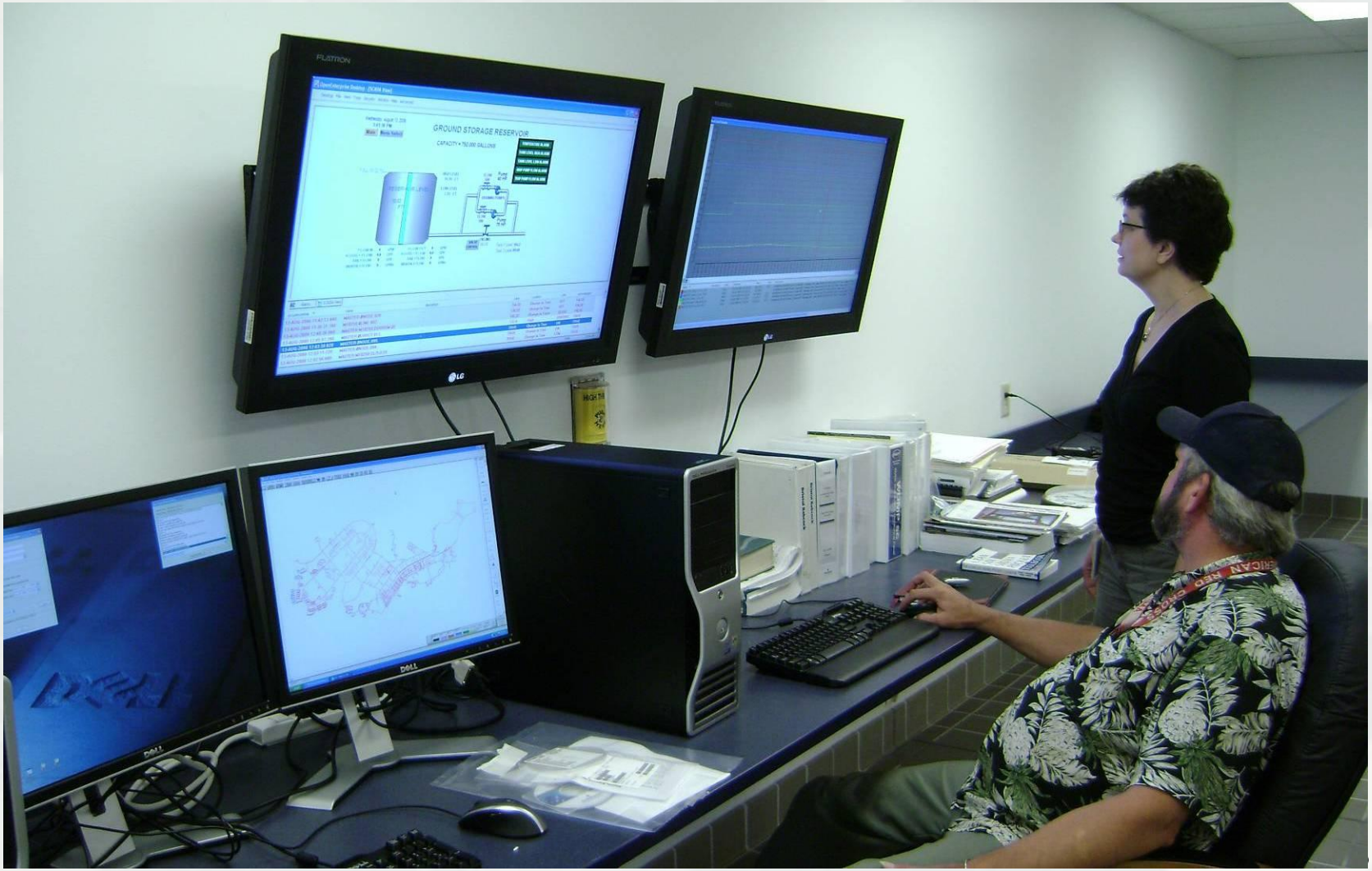
"Old" water

- Corrosion inhibitors and disinfectants are consumed
- Residence time controlled by system hydraulics
- Remote and low-use areas are especially problematic

Water Distribution Systems Have a Rich History



Monitoring at an Army Installation: Situational Awareness



Understanding The Real-time Status Of A Water Distribution Network

- Assessment of the structural and operational condition of underground water pipelines remains one of the most significant challenges facing utility managers in the private sector as well as DoD
- Condition assessment is challenging because the infrastructure is underground

If the condition of a pipeline is unknown, or if insufficient data is available to make an accurate assessment of the pipeline condition, then managers cannot be situationally aware and make sound decisions related to:

- Rehabilitation
- Replacement Funding
- Schedules
- Priorities For These Assets

We Have a Vision: A "Smart" Utility Network

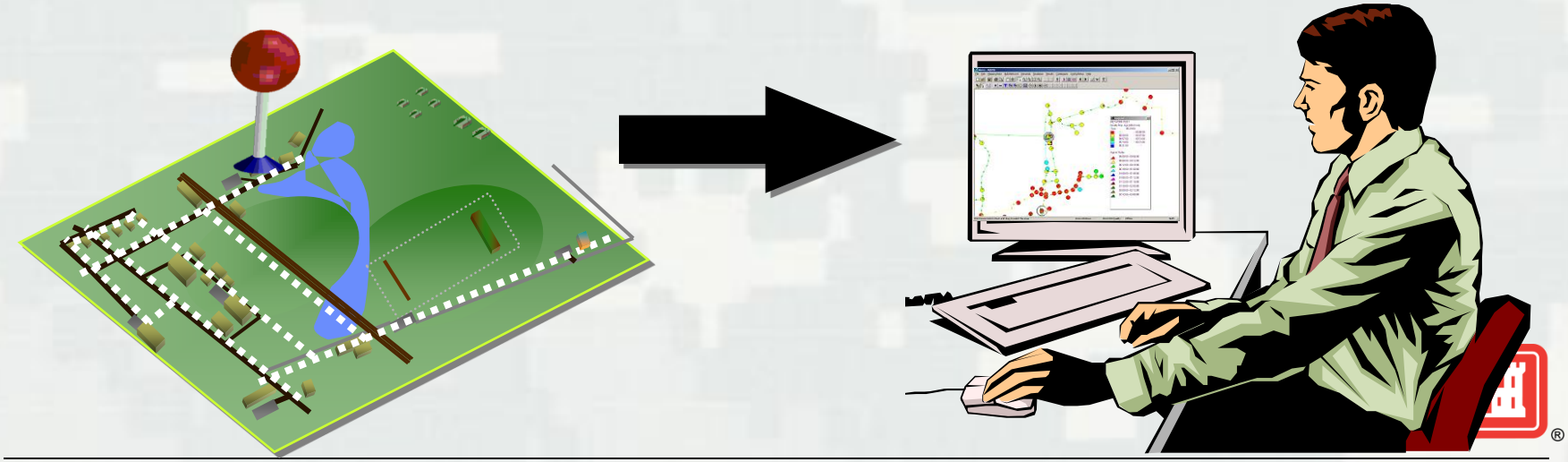
- Notifies the operator when something is wrong.
- Diagnoses the problem
- Solves the problem or recommends corrective action to the operator
- Allows operator to "experiment" with alternative solutions

"There is a problem at the main plant. Turbidity is 12 and chlorine residual is zero. "

"Contamination is suspected"

"Recommendation: Close valves at main plant. Do you want to do that?"

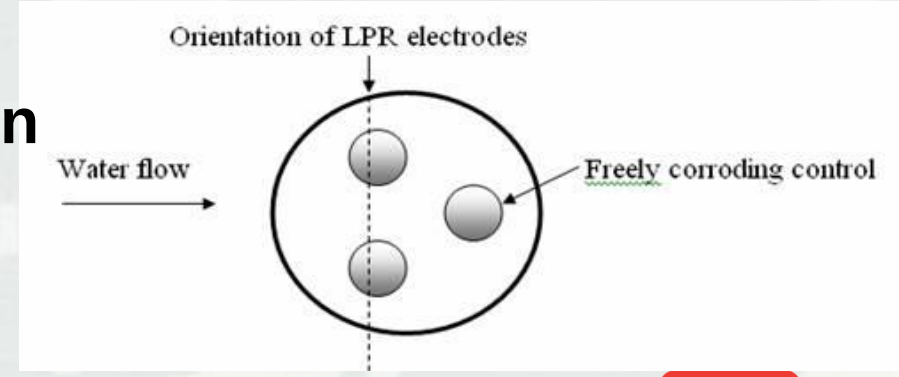
"Do you want to simulate what will happen if we do that? Do you want to try something else?"



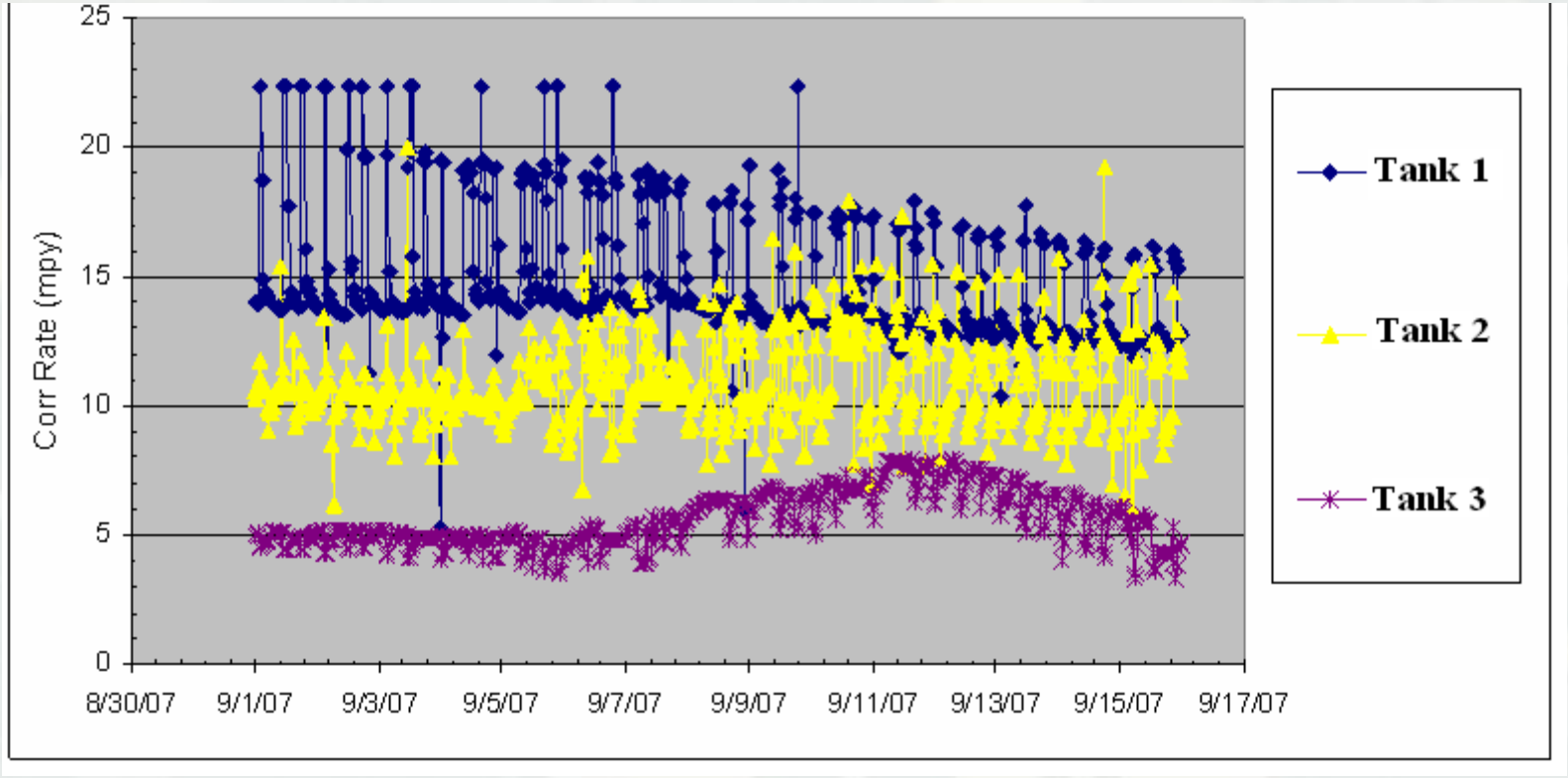
Integration of Sensors and Dynamic Models to Support Water Distribution Networks

Corrosion Rate Sensor

- Measures linear polarization resistance (LPR) or electrical resistance (ER)
- Calculates instantaneous corrosion rate (LPR)
- Rate can be integrated over time for cumulative metal loss
- "Corrosion imbalance" provides qualitative indication of pitting tendency
- Can be tied in with SCADA systems/ 4-20 mA output



Example corrosion rate data from LPR sensors



A wide variation in general corrosion rates was observed. The lowest rate consistent occurred in one of the water storage tanks at the site. The highest rate occurred at a pressure reducing valve with intermittent flow.

HACH PipeSonde In-Pipe Multiple Parameter Probe for Water Distribution Systems

Water Quality Sensor (Pipe Sonde)

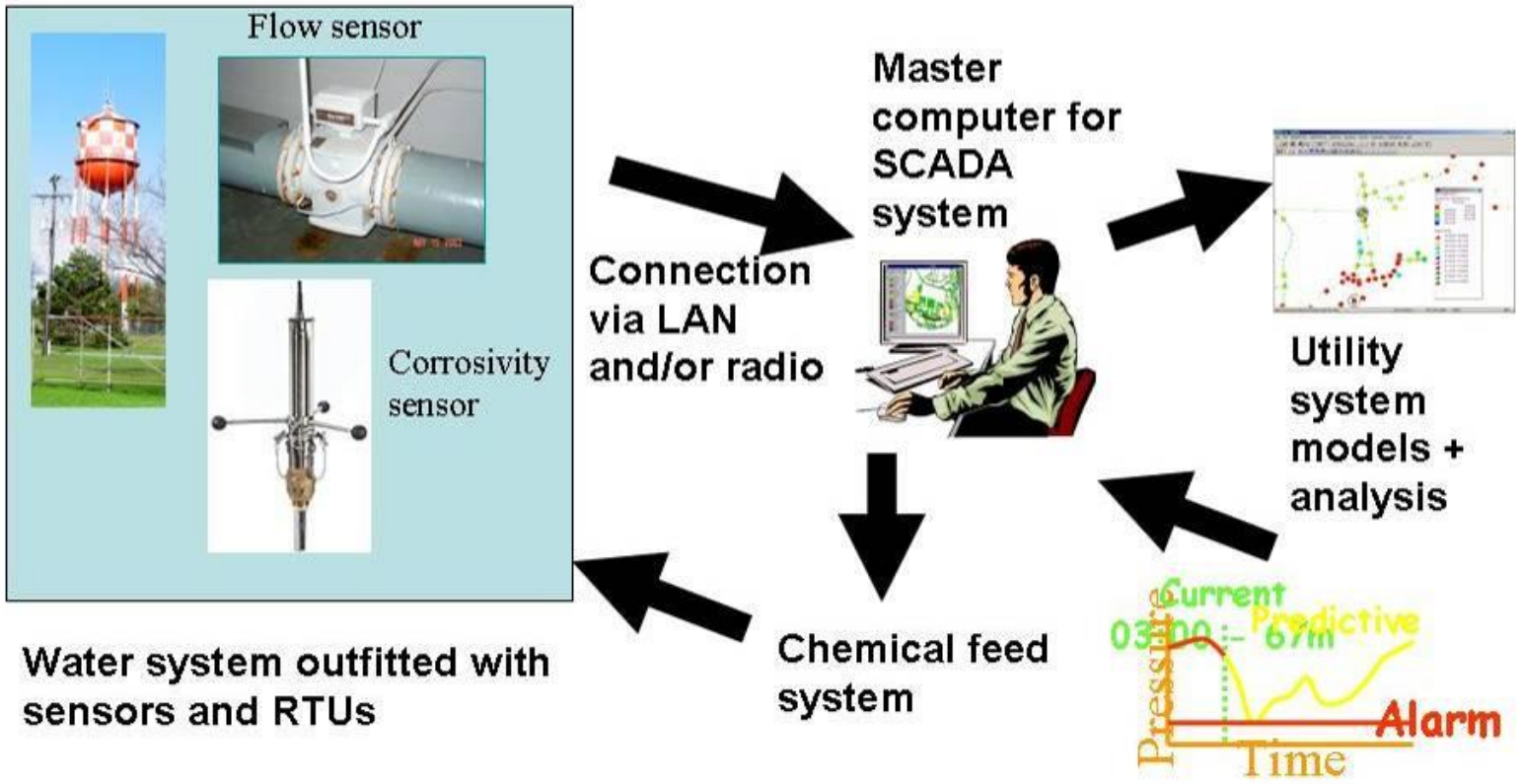
- Multi-parameter sensor that measures
  - pH
  - Conductivity
  - Turbidity
  - Dissolved oxygen
  - ORP
  - Water pressure & temperature
- Water and debris-tight for long-term field use
- Additional benefits for water security
- Can be tied in with SCADA systems/ MODBUS output

36 Inch Main Break

Major Causes Of Main Breaks

- Pipe Deterioration
- Weak Joints
- Earth Moving/settling
- Freezing
- Internal Corrosion
- Corrosive Soils
- Construction or Utility Digging
- Heavy Traffic Loads
- Changes in System Pressure
- Water Hammer
- Air Entrapment
- Seasonal Changes in Water Temperature

Schematic of Corrosion Detection and Management System



RTU = Remote Terminal Unit
SCADA = Supervisory Control and Data Acquisition
LAN = Local Area Network

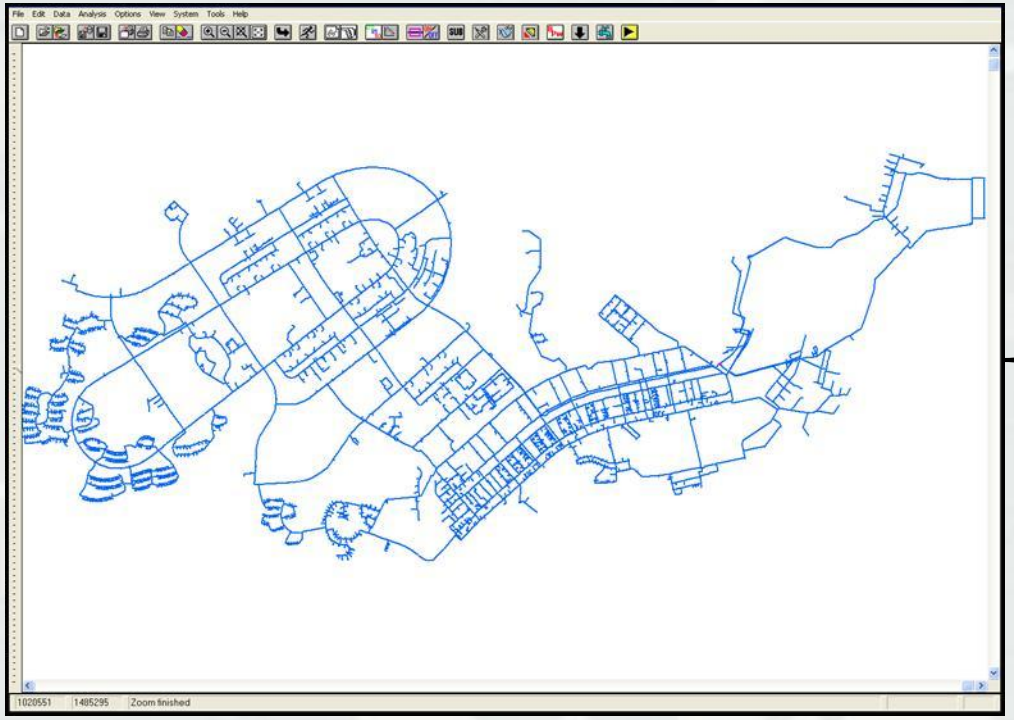
System Overview

Real-Time Model

SCADA System Sensors

Field Reports

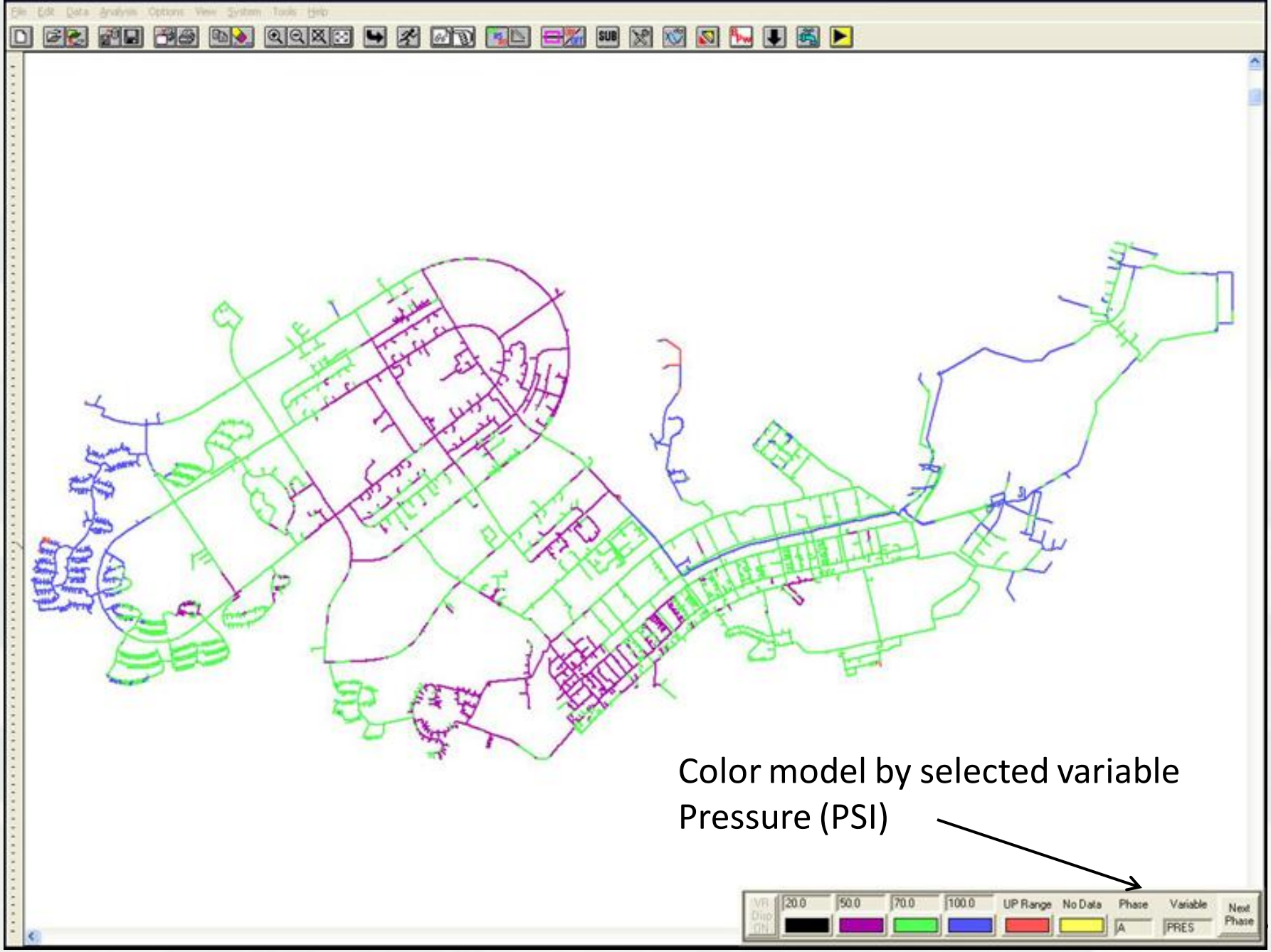
Lab Data



Hydraulics
- Pressure
- Flow
- Control

Water Quality
- Measures
- Constituents

Corrosion
- Measures
- Indexes
- History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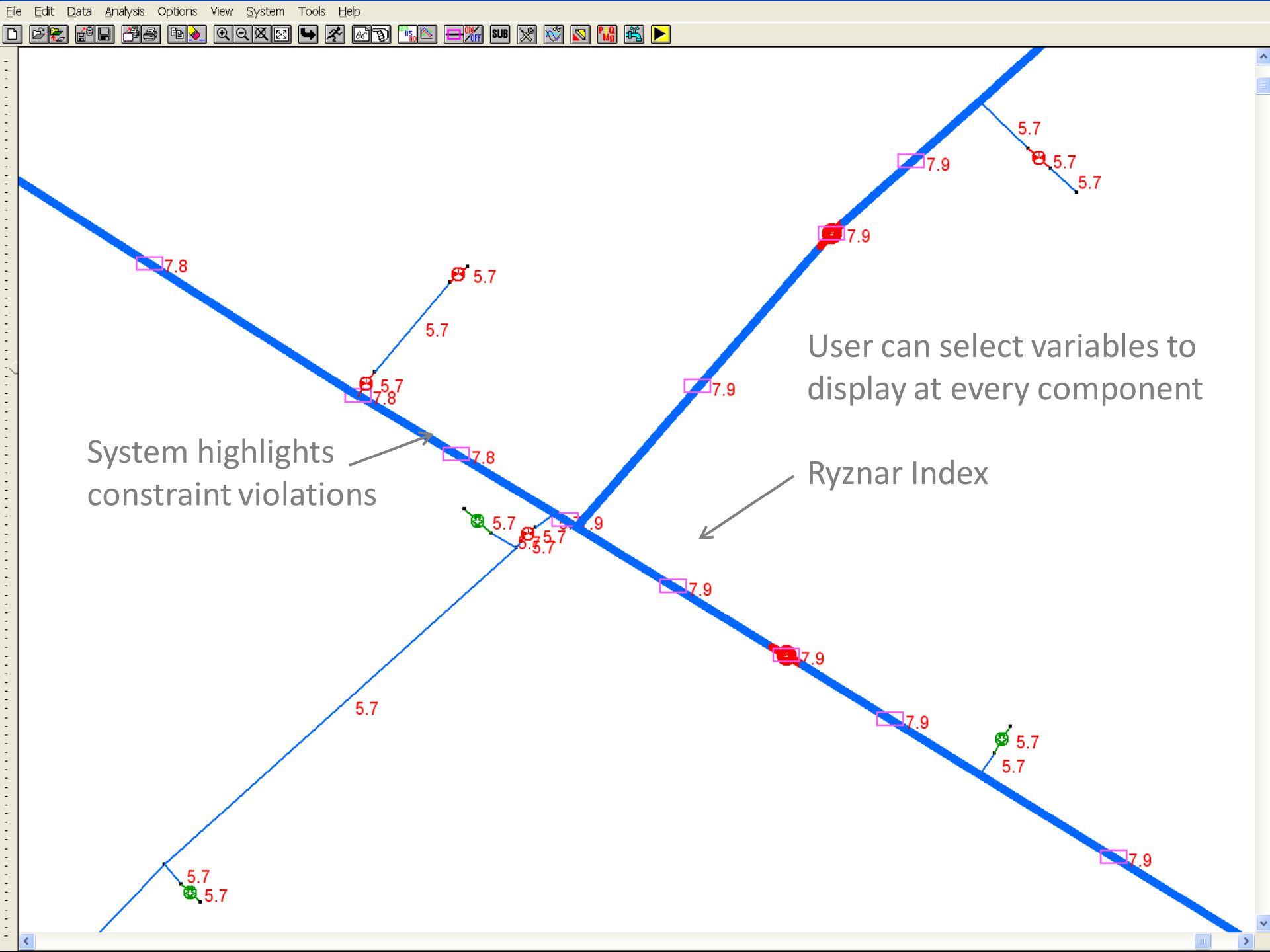

File Edit Data Analysis Options View System Tools Help
User can select variables to display at every component
System highlights constraint violations
Ryznar Index
7.8
5.7
7.9

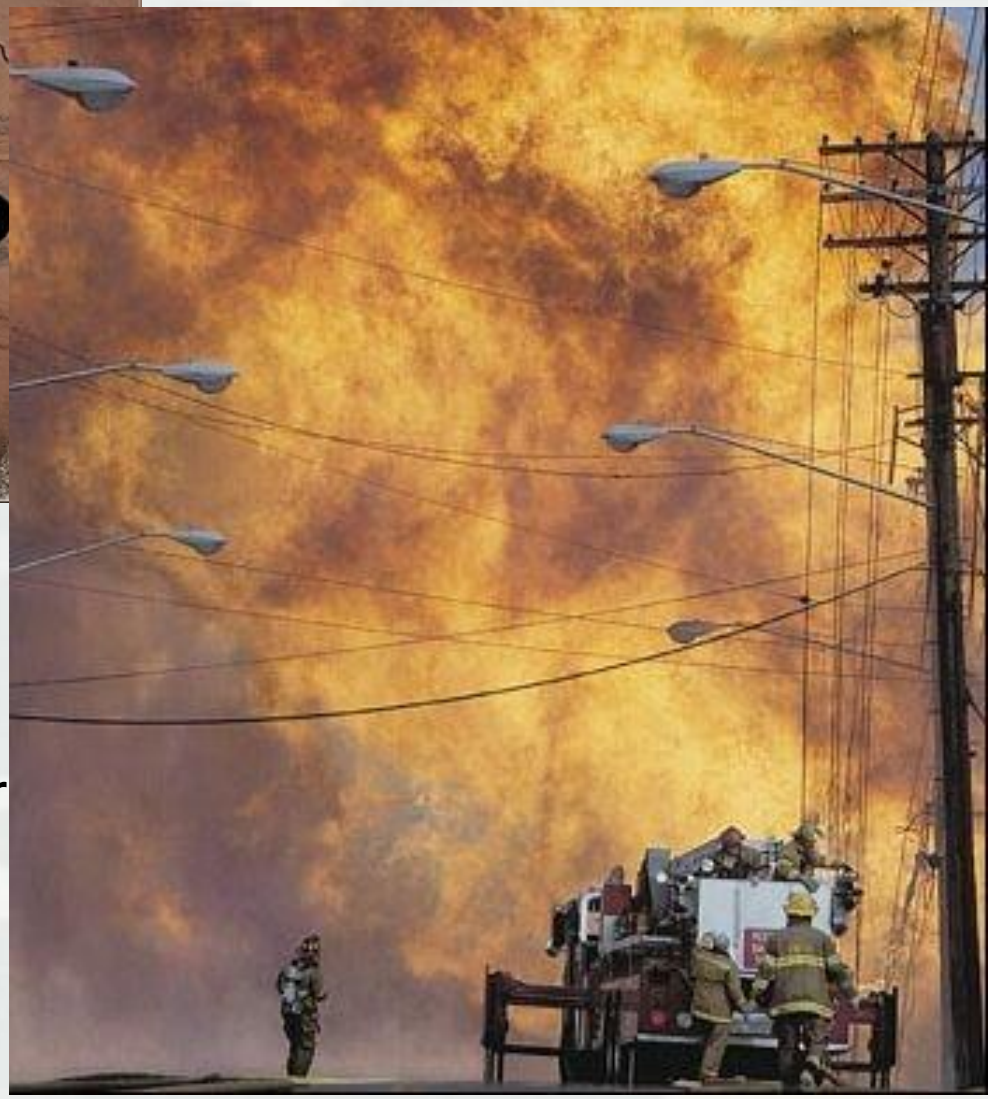
The Age of Terrorism Threat:

- Denial of service

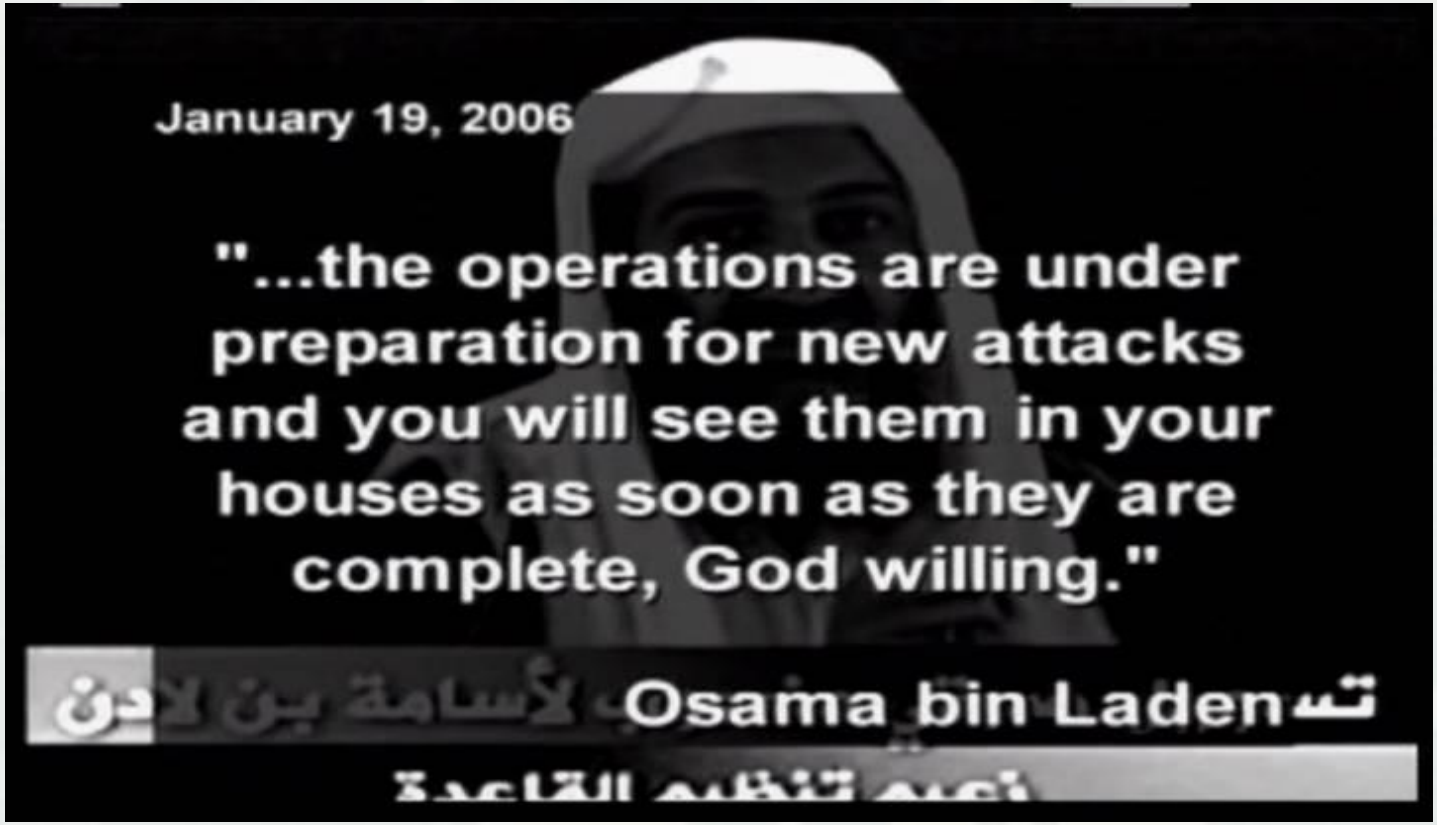
and collateral damage

High Visibility Attacks

- Other infrastructure is vulnerable
  - Main break creates a sink hole



- Treatment chemicals and other infrastructure (such as water distribution systems) are also vulnerable
  - Main break undermines a gas line ->


January 19, 2006
"...the operations are under preparation for new attacks and you will see them in your houses as soon as they are complete, God willing."
Osama bin Laden

A single terrorist (international, or domestic) can be up and running to attack a water system within days of arrival at target site.

Attack Scenario

- ***12 gallons of readily available toxic substance***
- ***pump ($150 rental)***
- ***wrench to open a fire hydrant ($10)***

- *One (1) terrorist, or equivalent, intent upon killing innocent people.*

Us Army/Navy CBR Contamination And Countermeasures Report

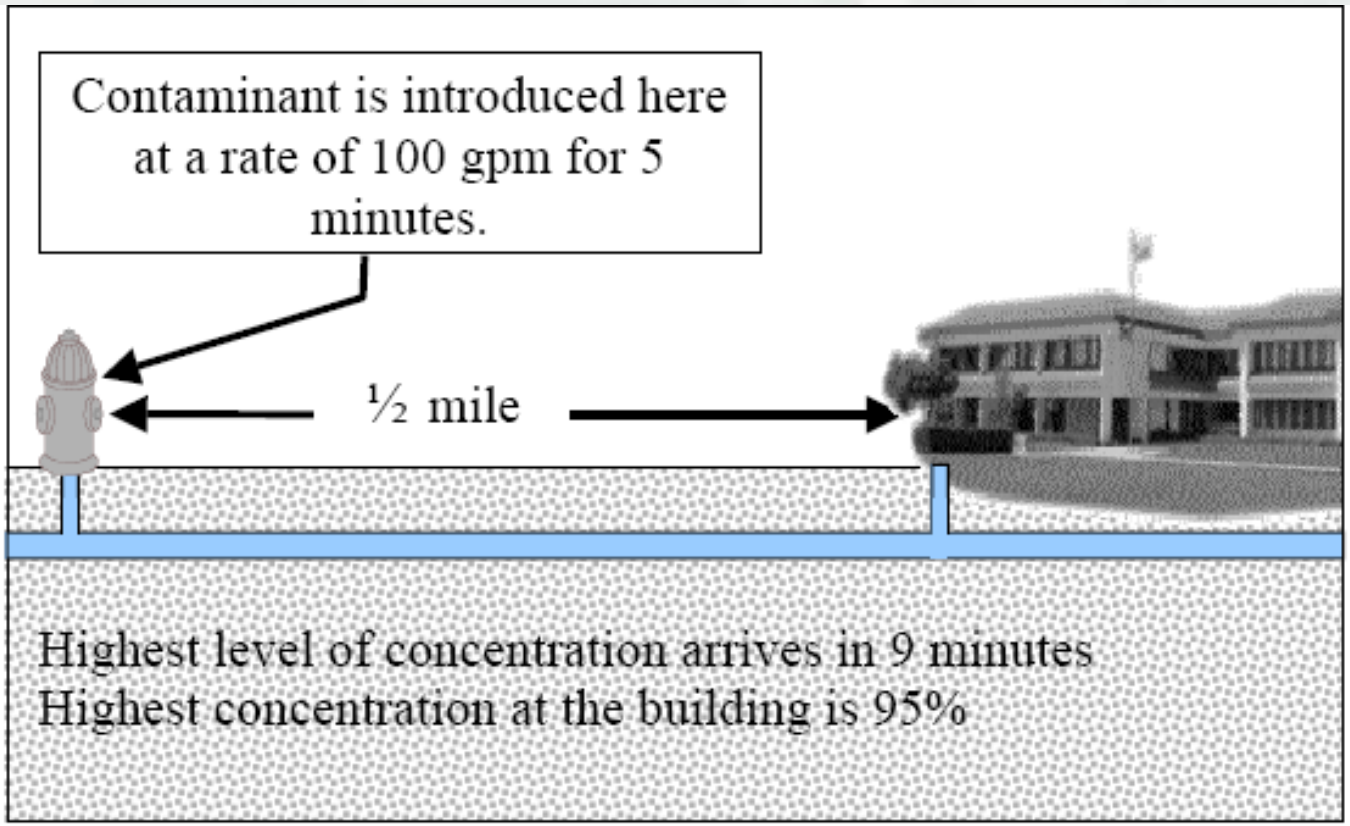
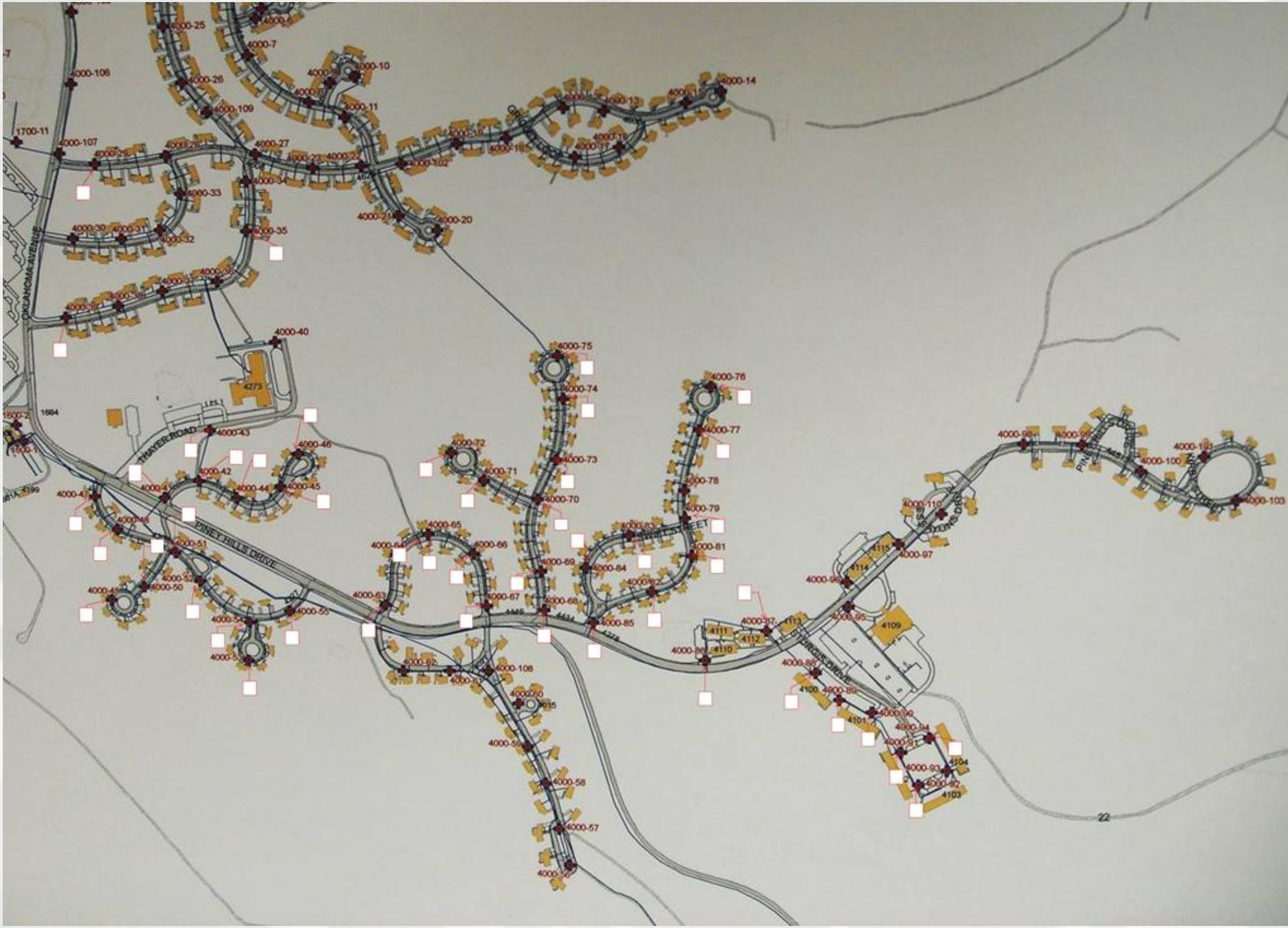


Figure1. Generalized model out put for an agent injected into a fire hydrant within a 1/2 mile of a targeted building.


OKLAHOMA AVENUE
THAYER ROAD
PINEY HILLS DRIVE
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4000-107
1700-11
4000-25
4000-26
4000-109
4000-7
4000-10
4000-11
4000-14
4000-27
4000-102
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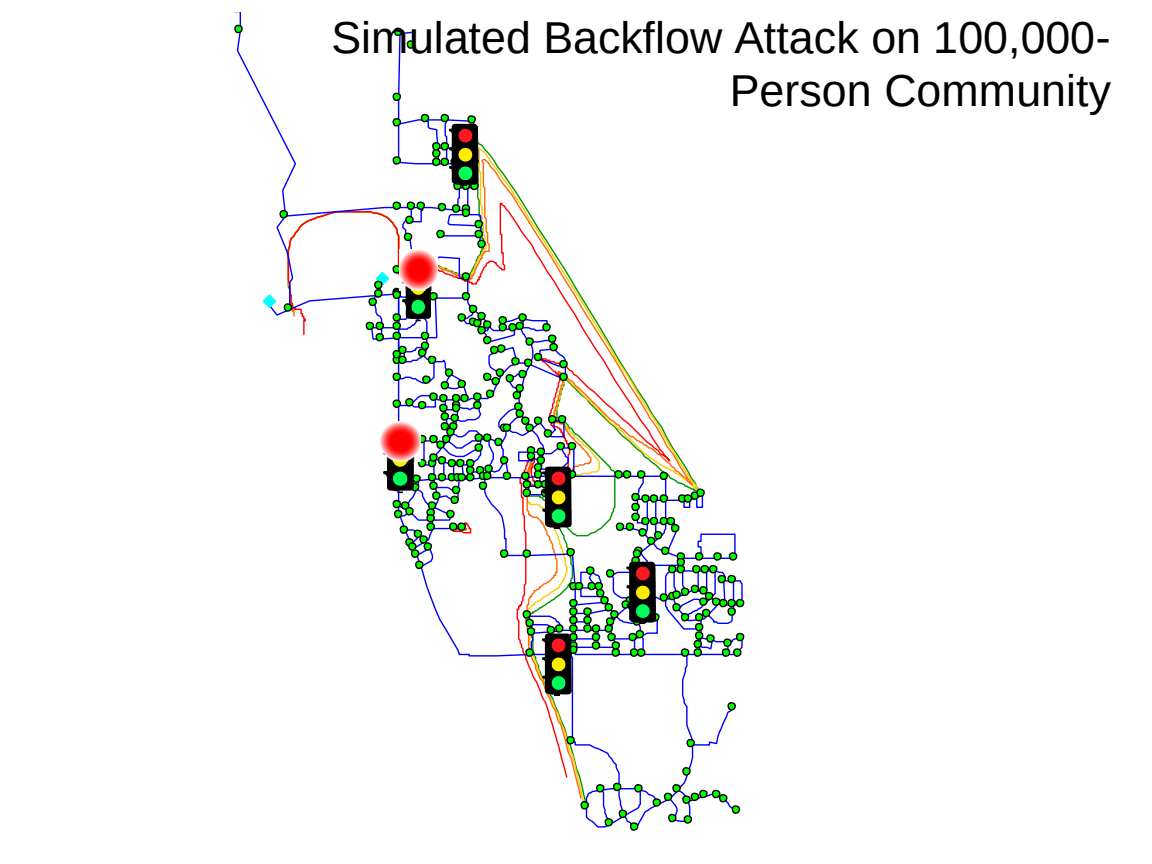
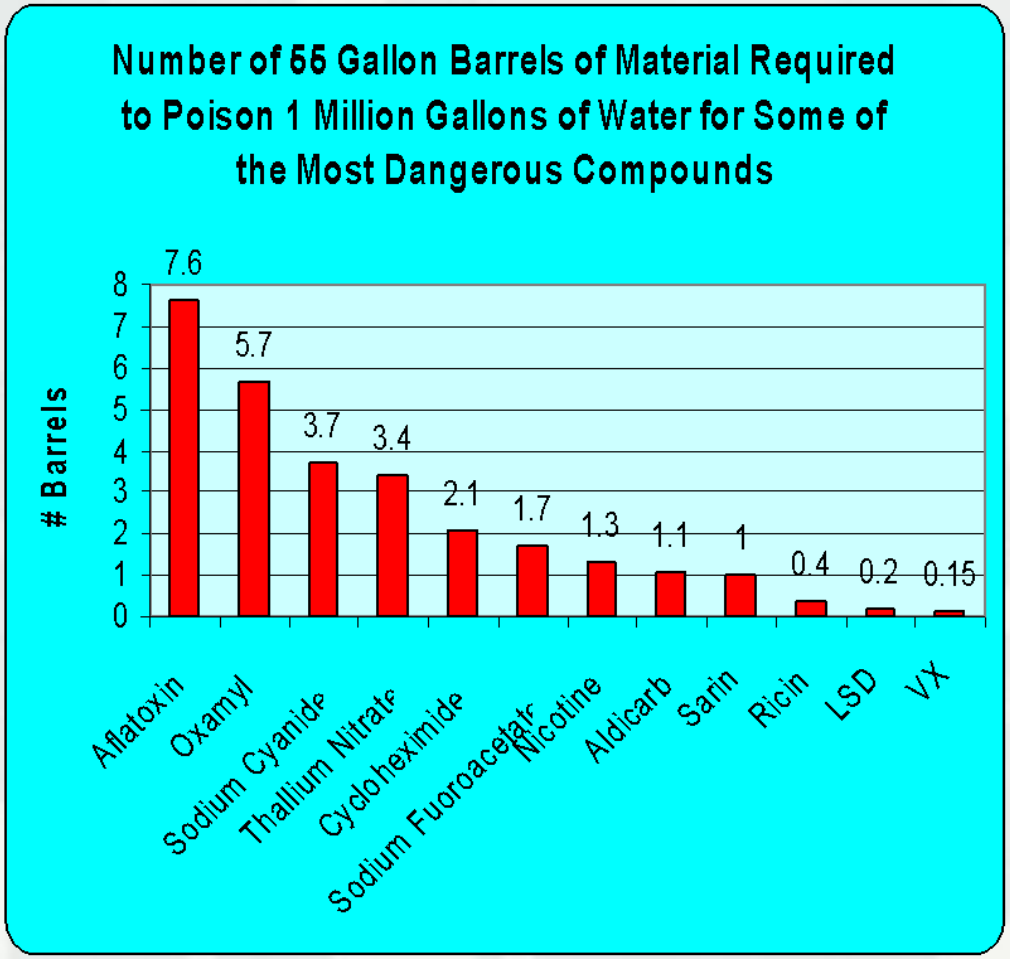
22

Backflow Attack Wave front

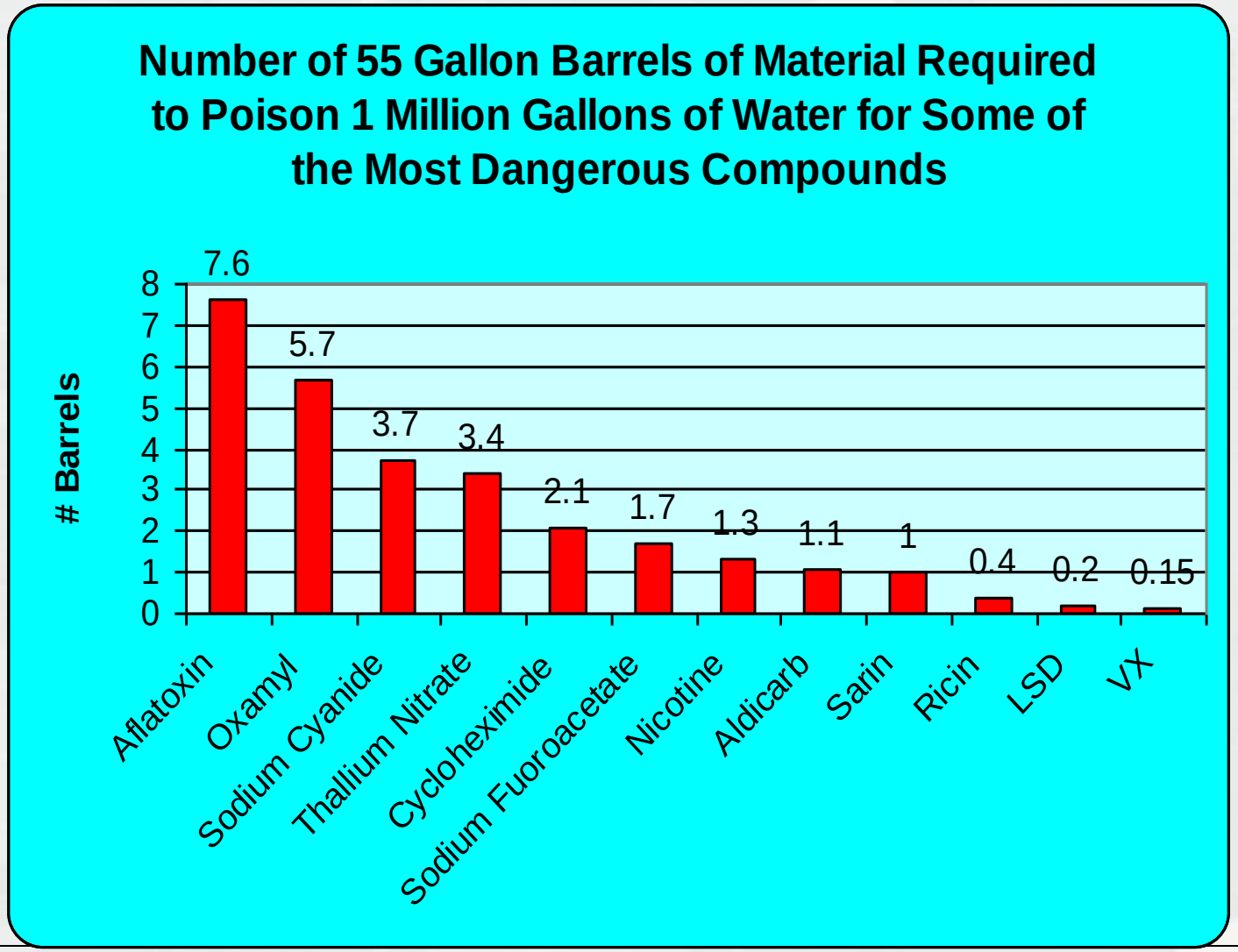


Results Predicted:
In a city of 100,000: Entire Populations Hit with Poisonous Water within 12 hours. 12% of Population Dead within 48 hours with a 1080 attack; 22% dead with VX attack.

Integrated Water Security



Threat - Large Number of Potential Contaminants



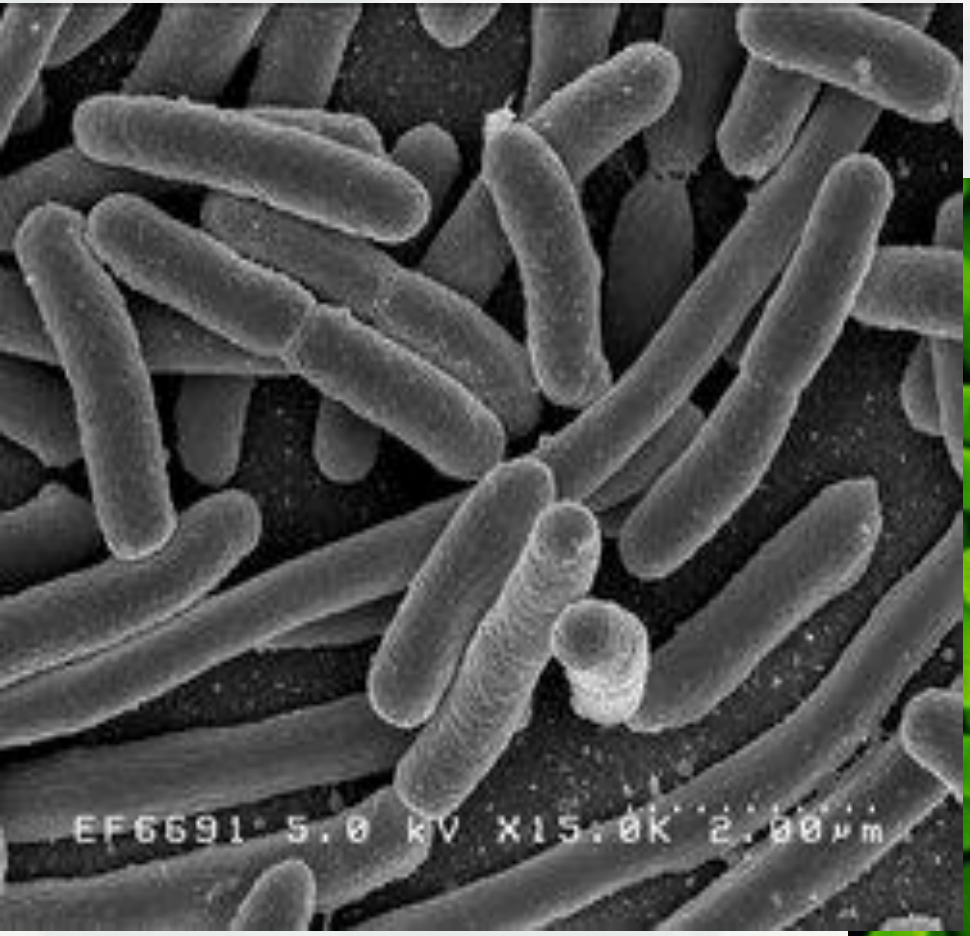
Tanker trucks are not necessary to Contaminate Water Supplies!

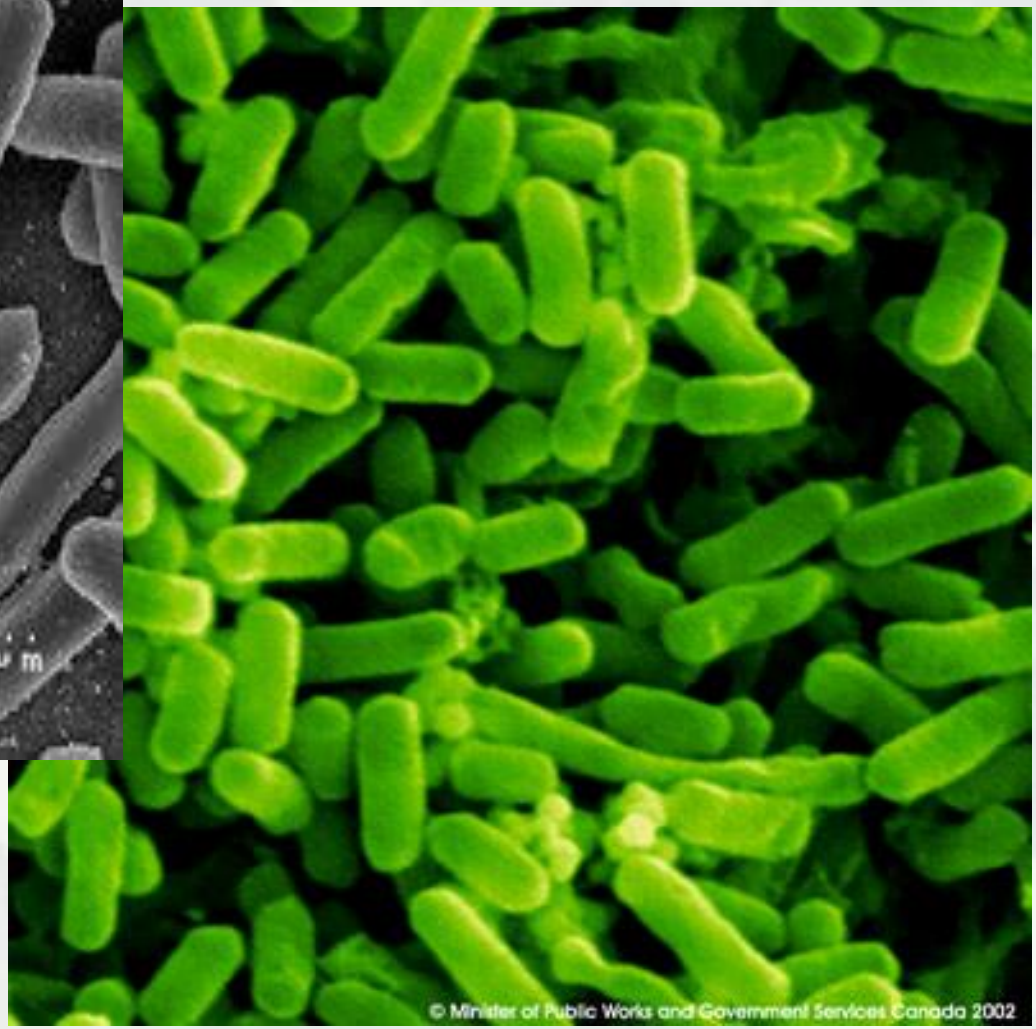
Measured as Solids

Liquid

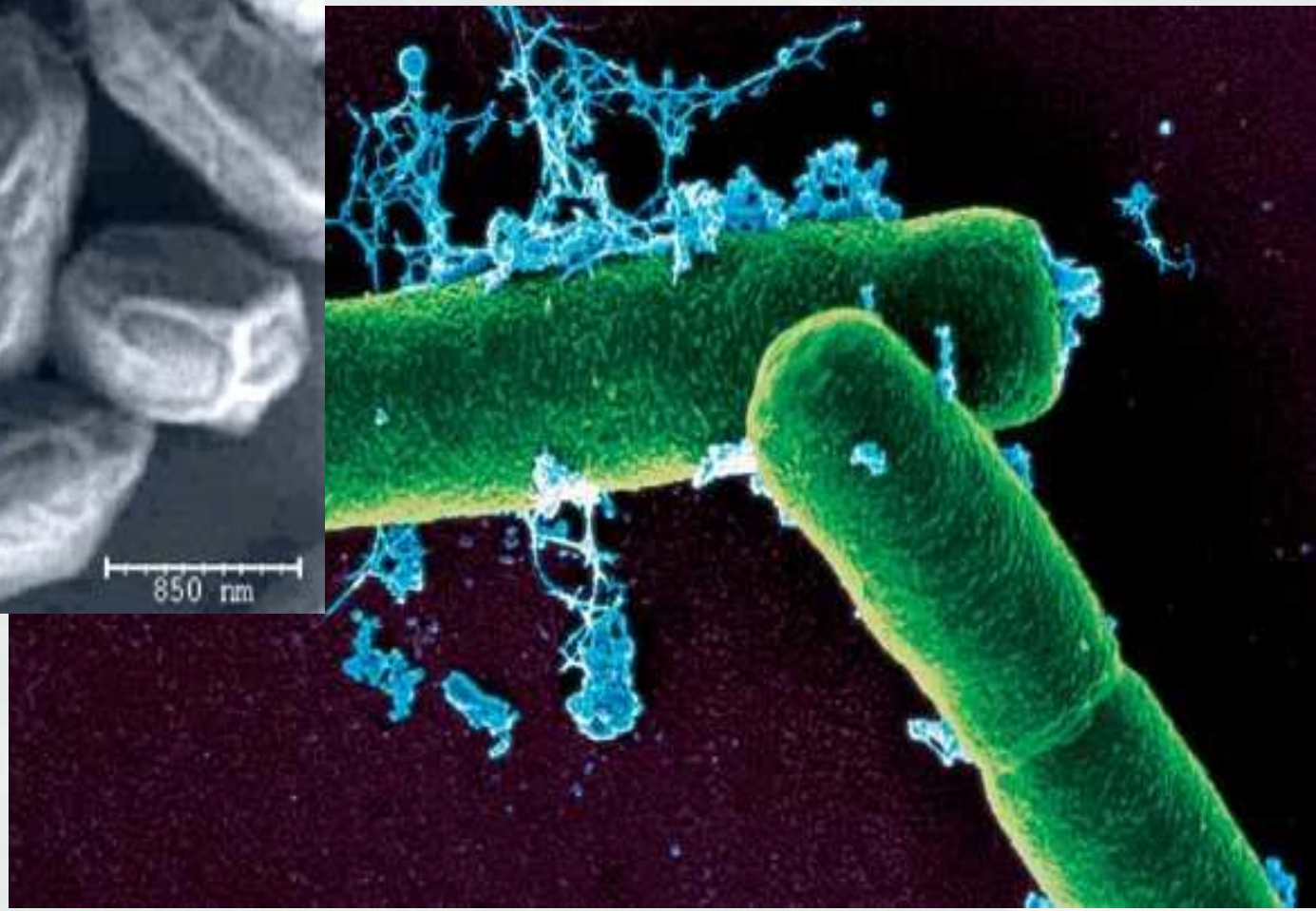
Most Serious Agents	55 Gal drums per 10^6 Gallons Water	General Comments
Aflatoxin	7.6	Potent Carcinogen
Aldicarb	1.1	
Cycloheximide	2.1	
LSD	0.2	Highly Toxic, Psychoactive
Mercuric Chloride	0.2	
Oxamly	5.7	Readily available
Ricin	0.4	
Sodium Cyanide	3.7	Fast acting, readily available
Sodium Fluoroacetate	1.7	Tasteless, Colorless, Odorless
Thallium Nitrate	3.4	
Sarin	1	
VX	0.15	

Escherichia Coli

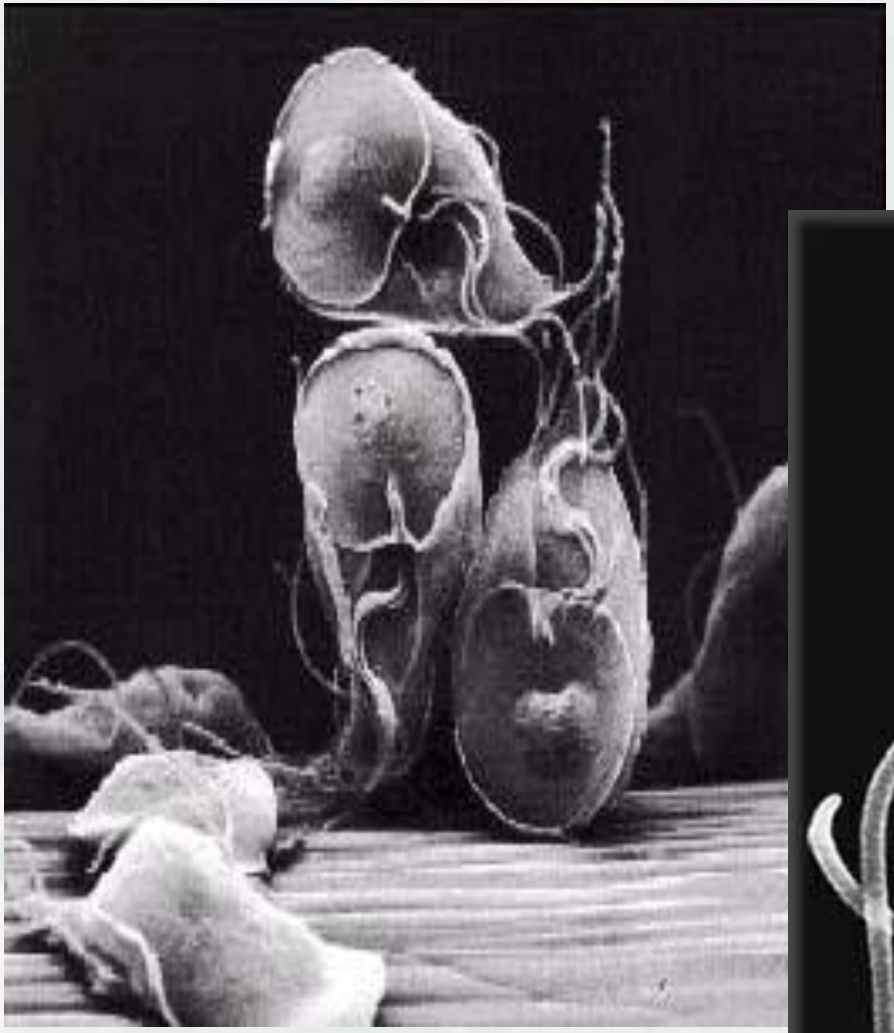


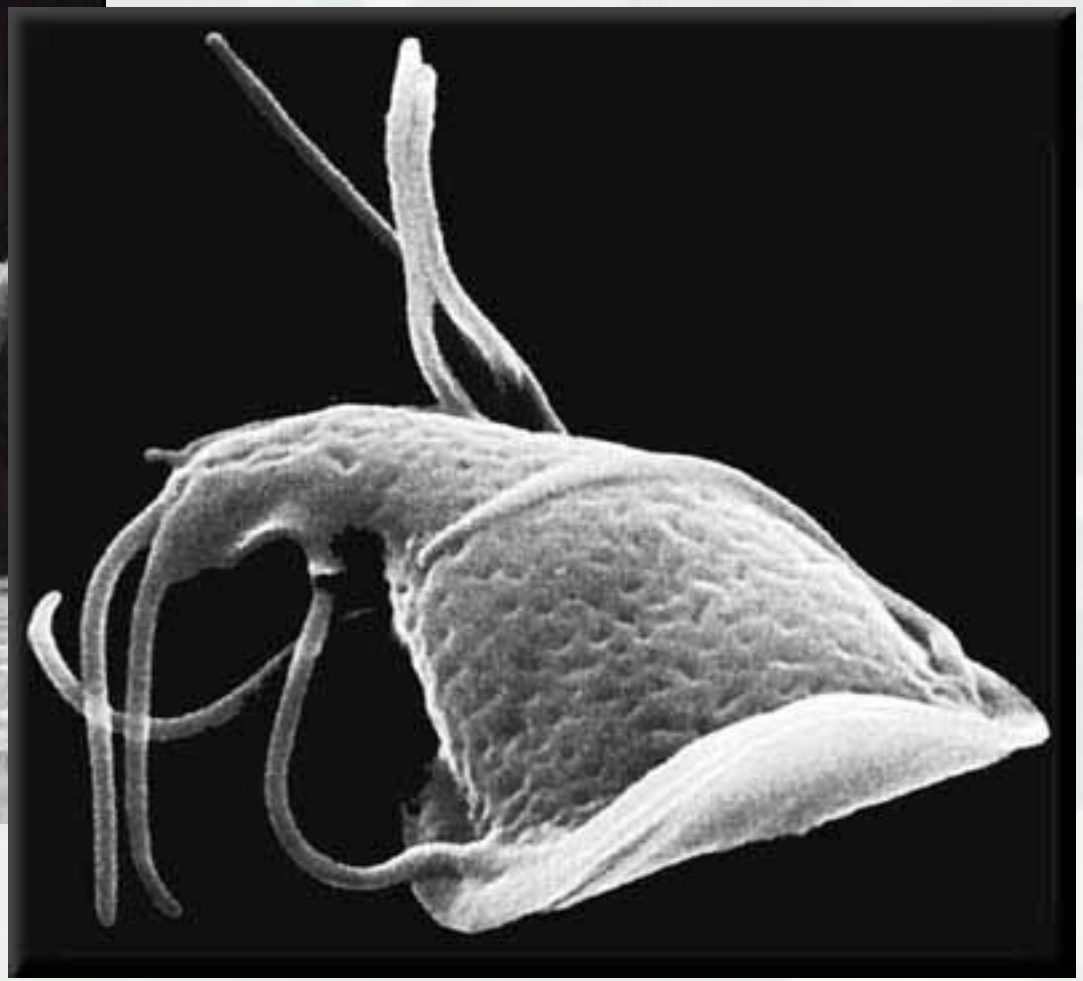


Anthrax - Spores and Vegetative



Giardia duodenalis





The Threat – Current Estimates

- AwwaRF Project 2810
  - 279 Documented incidents from ~1960's to 1999
  - 19 deaths, 166 illnesses confirmed
- Kroll (Hach HST) "Securing Our Water Supply: Protecting a Vulnerable Resource"
  - 24 incidents from 2000 to present
- GAO Report GAO-03-29
  - 75% of experts (32/43) identify the water distribution system as being most vulnerable (as opposed to source waters or other system components, treatment chemicals, etc.).

Backflow Attack History

("It's cheap and easy")

- **1980 – A disgruntled employee deliberately contaminated water mains in Pittsburgh by injecting weed killer into fire hydrants.**
- **1983 – Israel uncovered and Israeli Arab plot to poison Galilee water with an unidentified powder.**
- **1985 – Trace levels of plutonium were intentionally introduced into New York City's water supply.**
- **2002 – Al Qaeda operatives were arrested with plans to attack the U.S. Rome embassy's water supply with a cyanide compound.**
- **2002 – Al Qaeda operatives were arrested with plans to attack the water networks surrounding the Eiffel Tower neighborhood in Paris, France.**
- **2003 – Jordan foiled an Iraqi plot to poison drinking water supplies form Zarqa feeding U.S. military bases in the Eastern Desert**
- **2003 – A FBI bulletin Warned of Al Qaeda plans found in Afghanistan to poison U.S. food and water supplies.**
- **2006 – Strychnine found in Danish reservoir due to dumping of rat poison**
- **2008 - Pakistani police arrested five suspected militants who planned to use cyanide powder to poison water during the Shiite Muslim festival of Ashura**

GuardianBlue Water Distribution Monitoring Process

The System is used to detect and preliminarily classify anomalous events in the drinking water distribution system increasing security and streamlining operations

Certificate of Conformance

This will certify that, on this date,

the United States Department of Homeland Security issued to

HACH COMPANY

a Delaware corporation

a **Certification** *for its*

Hach GuardianBlue™ Early Warning System

as an **'Approved Product for Homeland Security'** *under the*

Support Anti-terrorism by Fostering Effective Technologies Act of 2002 (the SAFETY Act).

Jay M. Cohen — 10/31/2006

Jay M. Cohen — **Date**

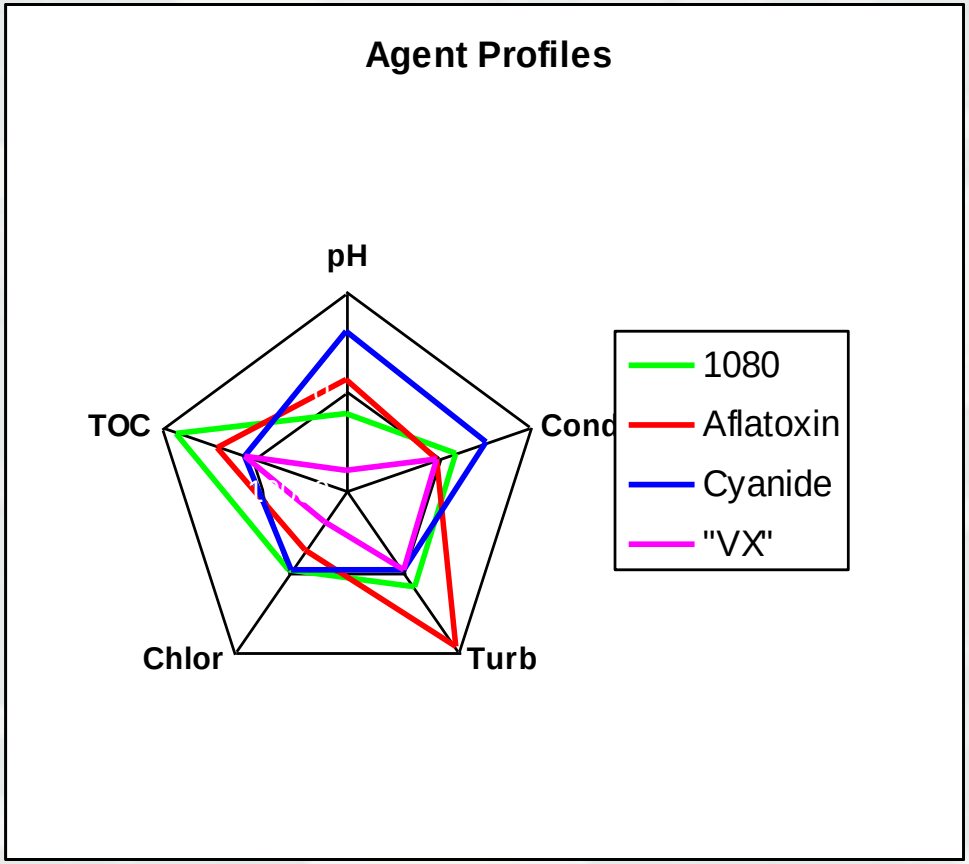
Under Secretary for Science and Technology

Beijing Olympics

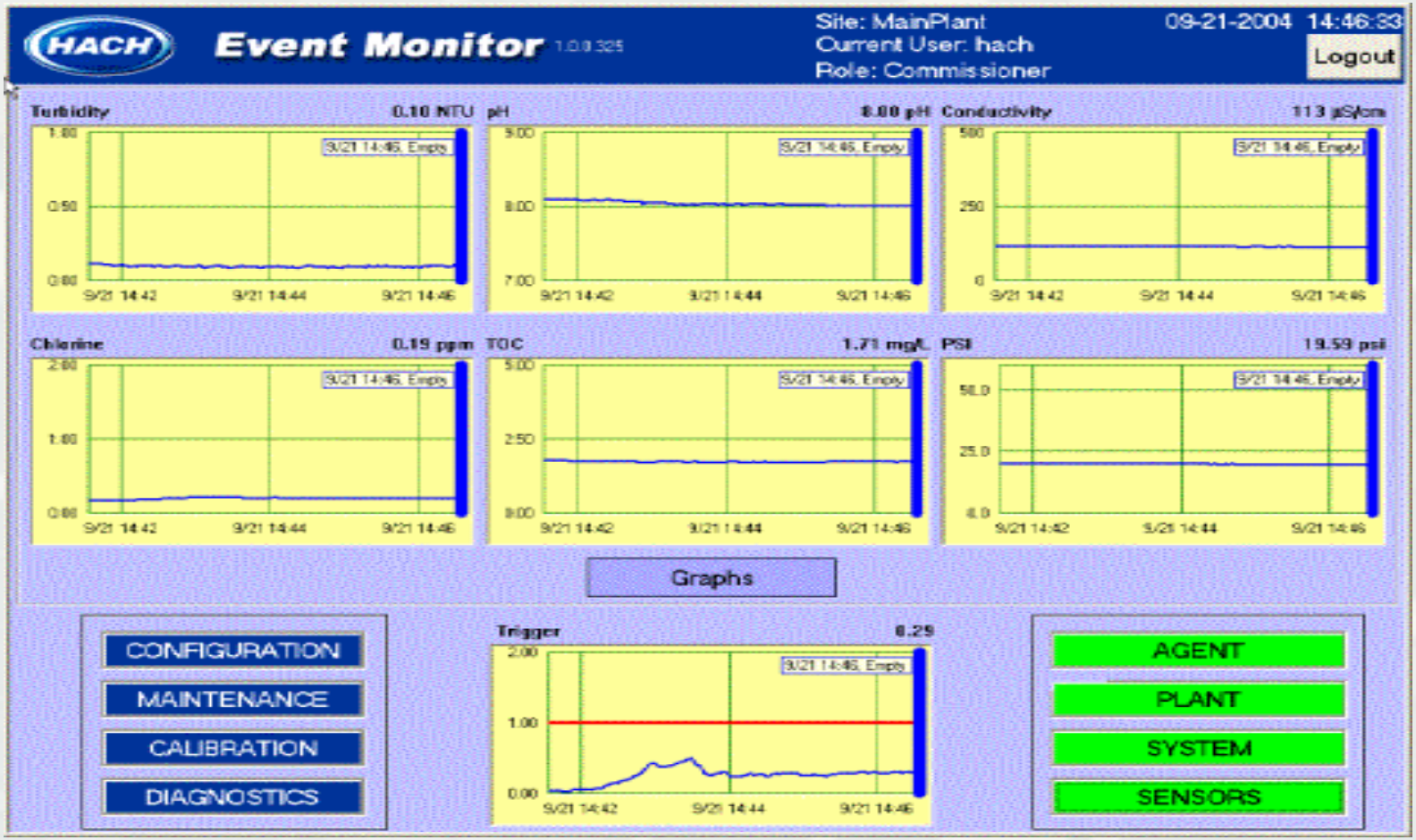
- GuardianBlue Systems selected for securing drinking water during the recent Beijing Olympic games.

Approach: Detection by “Fingerprint Signature” of the Toxin

- HACH sensor capable of determining contaminant type from water quality data (TOC, chlorine, pH, etc. as a “generalized vector”).
- Hach sensor is equipped with a library of water quality responses to ~100 classes of agent.



Water Quality Distribution Monitoring Process (Event Monitor) Trigger System



View all measurements and trigger signal from the main screen.

What can we see?

- **Tested in the lab: (80)**

Mercury Chloride (Nitrate and other mercury compounds), Arsenic Trioxide, Strychnine Nitrate, Thallium Nitrate (Chloride and other thallium compounds), Cyanide Compounds, LSD (Acid), Carbofuran, Dichlorvos, Methidathion, Methamidophos, Methomyl, Oxamyl, Cacodylic Acid, Cadmium Chloride (and other cadmium compounds), Diquat, Endothall, Paraquat, Sodium Fluoroacetate (1080), Colchicine, Aldicarb, Nicotine, Lead Nitrate, Bromadiolone, Phorate, Azinphosmethyl, Carbaryl, Malathion, Methyl Parathion, Parathion, Terbufos, Ethoprophos, Fenamiphos, Cyanazine, Aflatoxin, Lindane, Heroin, Acrolein, **Diesel fuel**, BHI Media, Guthion, Aldicarb-Sulfone, **Gasoline**, *B. globii, E. coli,* Acephate, Ammonuim Thiocyanate, Anabasine, Bronopol, Cycloheximide, Endothall, Dicamba, Difenzoquat methylsulfate, Enfamil (Media), Just Whites (media), Mephospholan, Phospholan, Anilofos, Chlorfenvinphos, Formetanate Hydrochloride, Acrolein, Chloropicrin, Sodium chloroacetate, Thyoglycolate medium, Crotoxyphos, Glyphosate, Jimsonweed, Methanol, Osmium tetroxide, Potassium Ferricyanide, Avitrol (4-aminopyridine), Cobalt sulfate heptahydrate, **Beechwood creosote**, Dicrotophos, **Kerosene, Ground Water, Raw Sewage**, Lipopolysaccharides of E. coli (botox surrogate), Soybean lecithin (Ricin surrogate) Thallium sulfate, **Sarin, Soman,** Anthrax, V. Cholera, Cyrptosporidium, MS2 phage, Ricin, SEB, VX

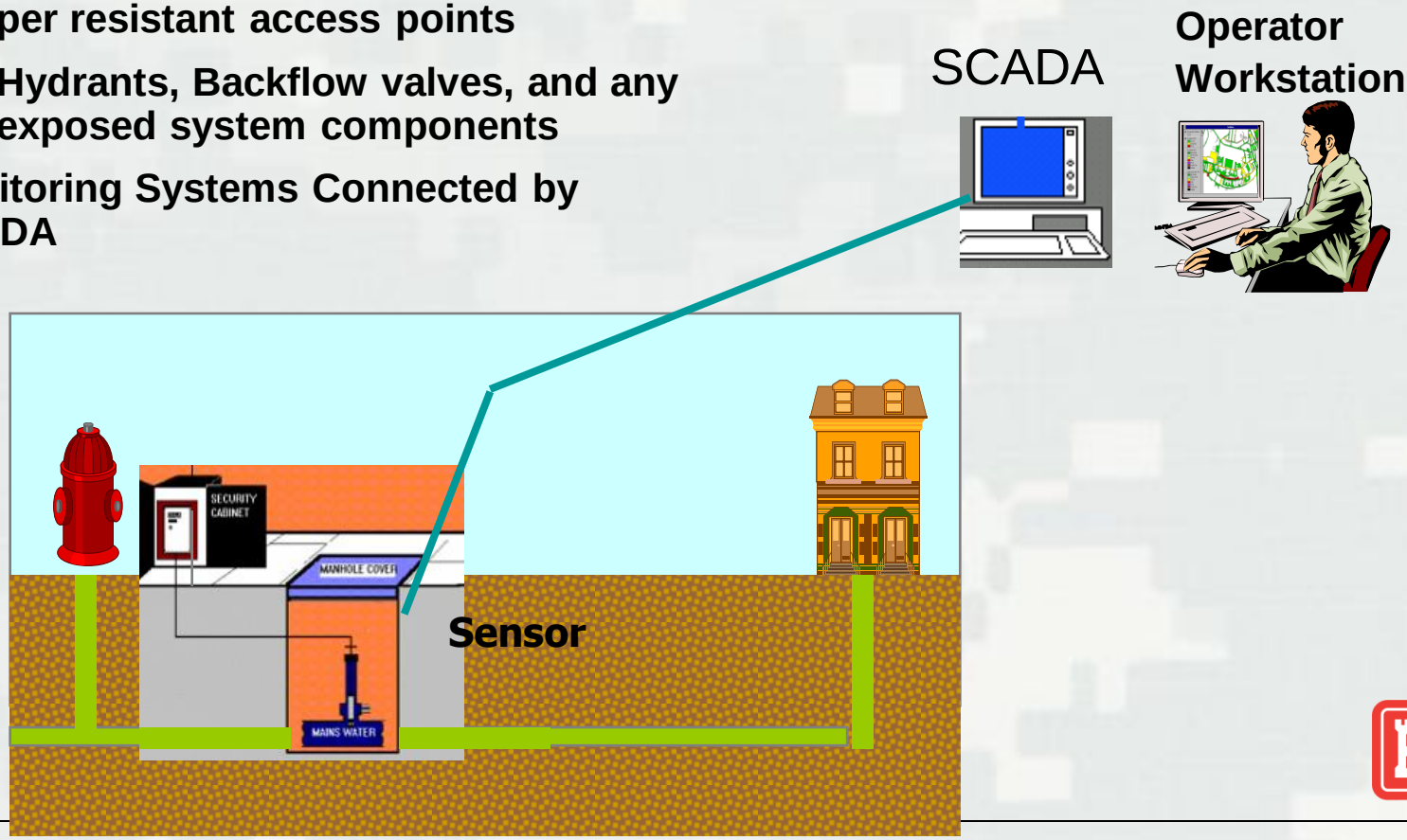
Goal: Integrated System Security Defense in Depth

Layered Protection

- An informed public is alert to system threats
- Tamper resistant access points
  - Hydrants, Backflow valves, and any exposed system components
- Monitoring Systems Connected by SCADA

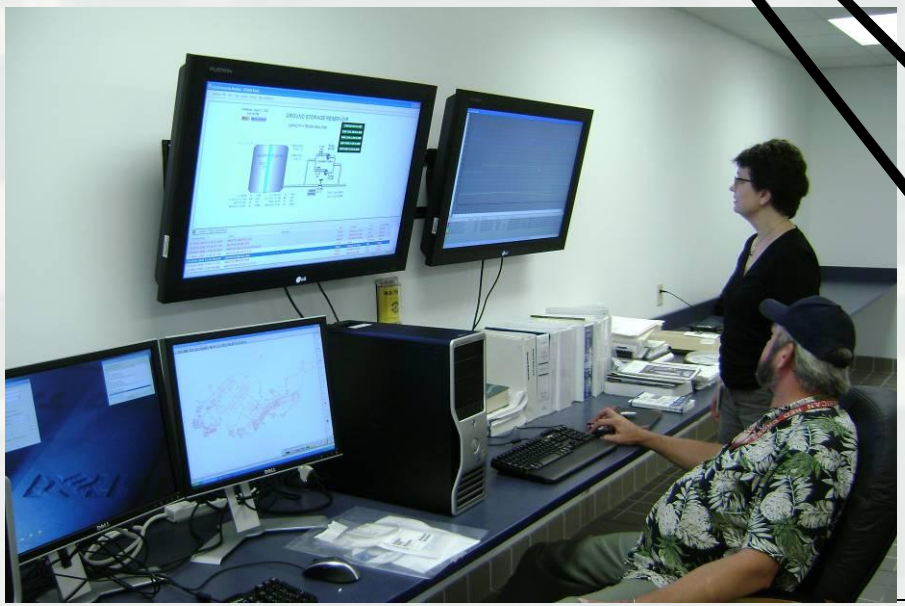
Situational Awareness

- Sensor-enabled dynamic models coupled with countermeasures



Objective: Situational Awareness & Actionable Information

- Lab Validated Fate and Transport Models

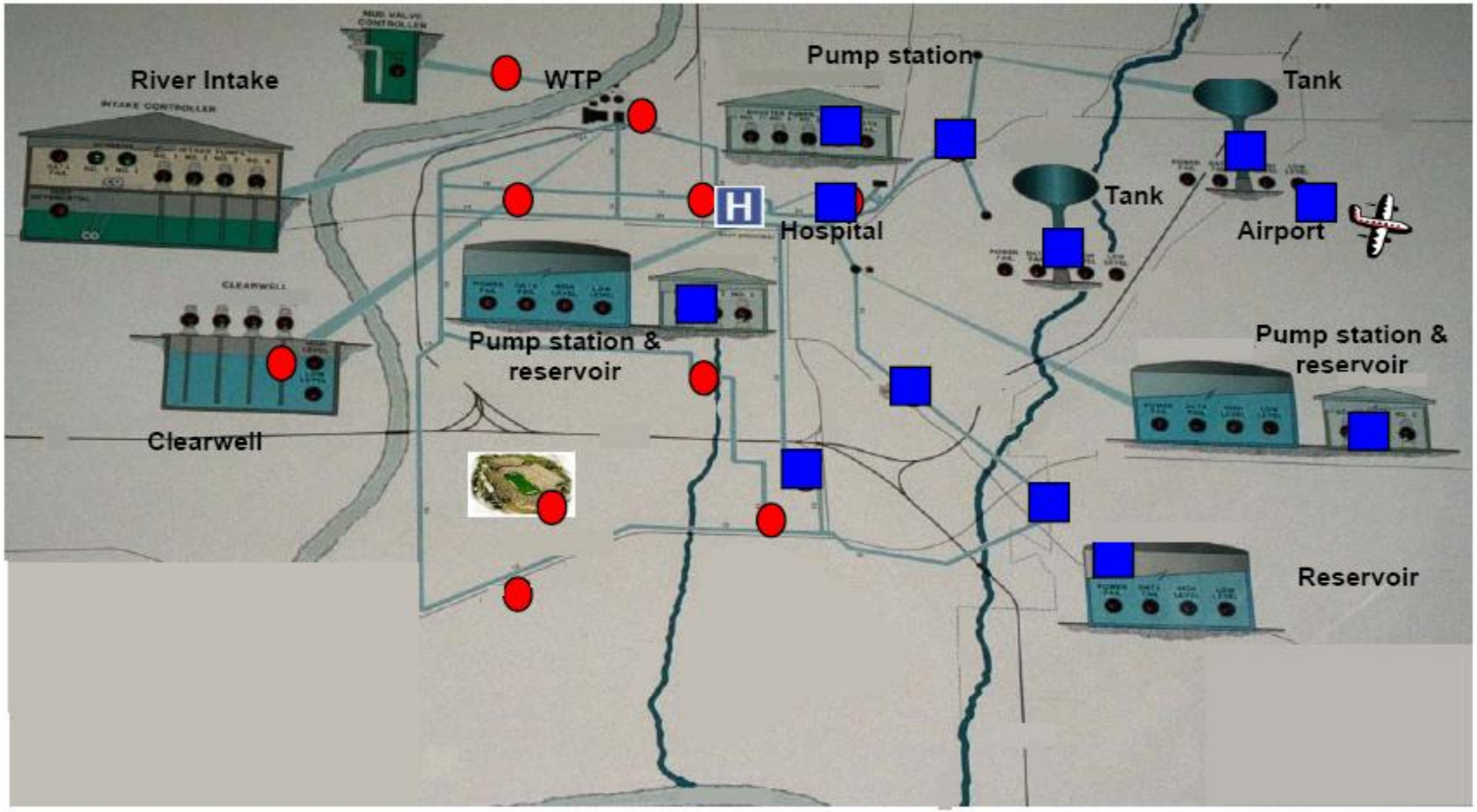


Workstation with a single user interface for:

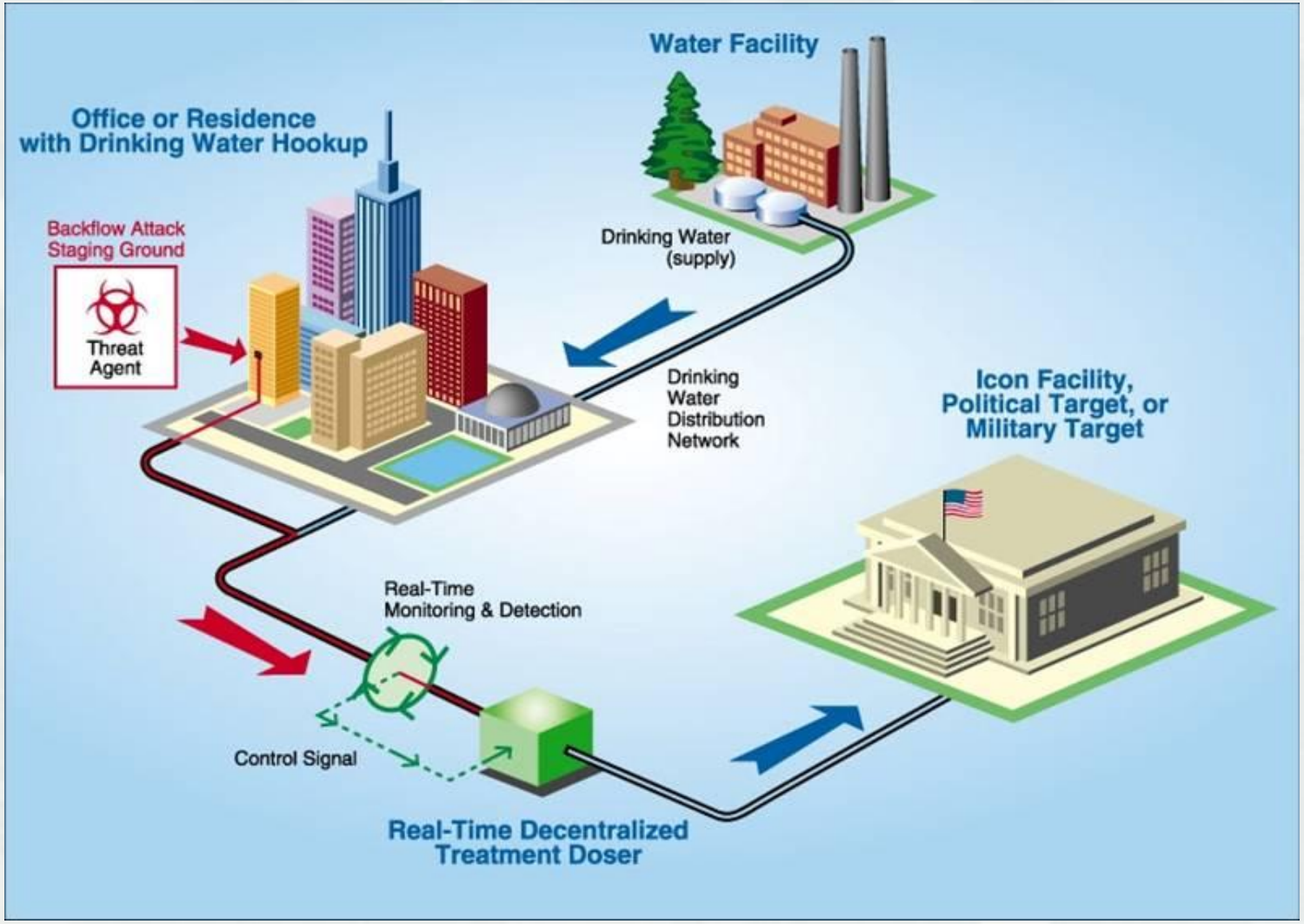
- Vulnerability Assessments
- Real-Time Operation
- Detection
- Countermeasures

Best Approach is a Network Approach

Not a choice of just one, or two instruments

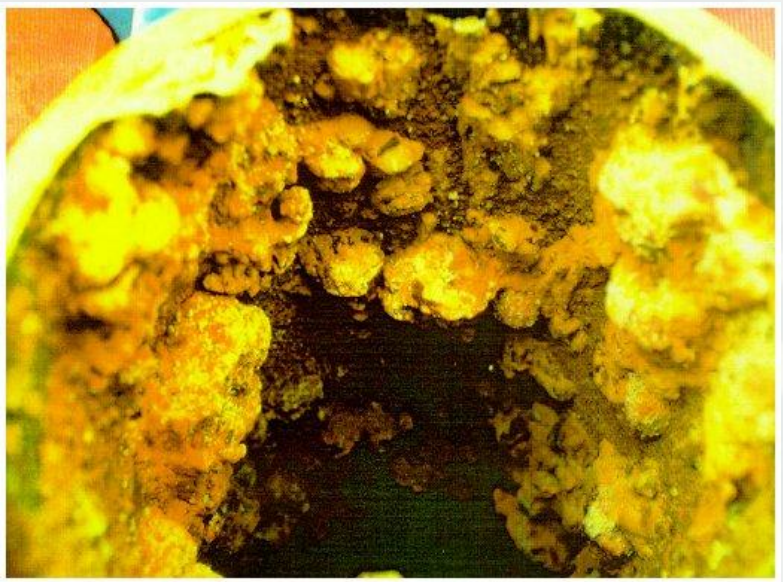


Summary: Our Vision:



Modeling of Fate and Transport of CB Contaminants For Improved Simulations

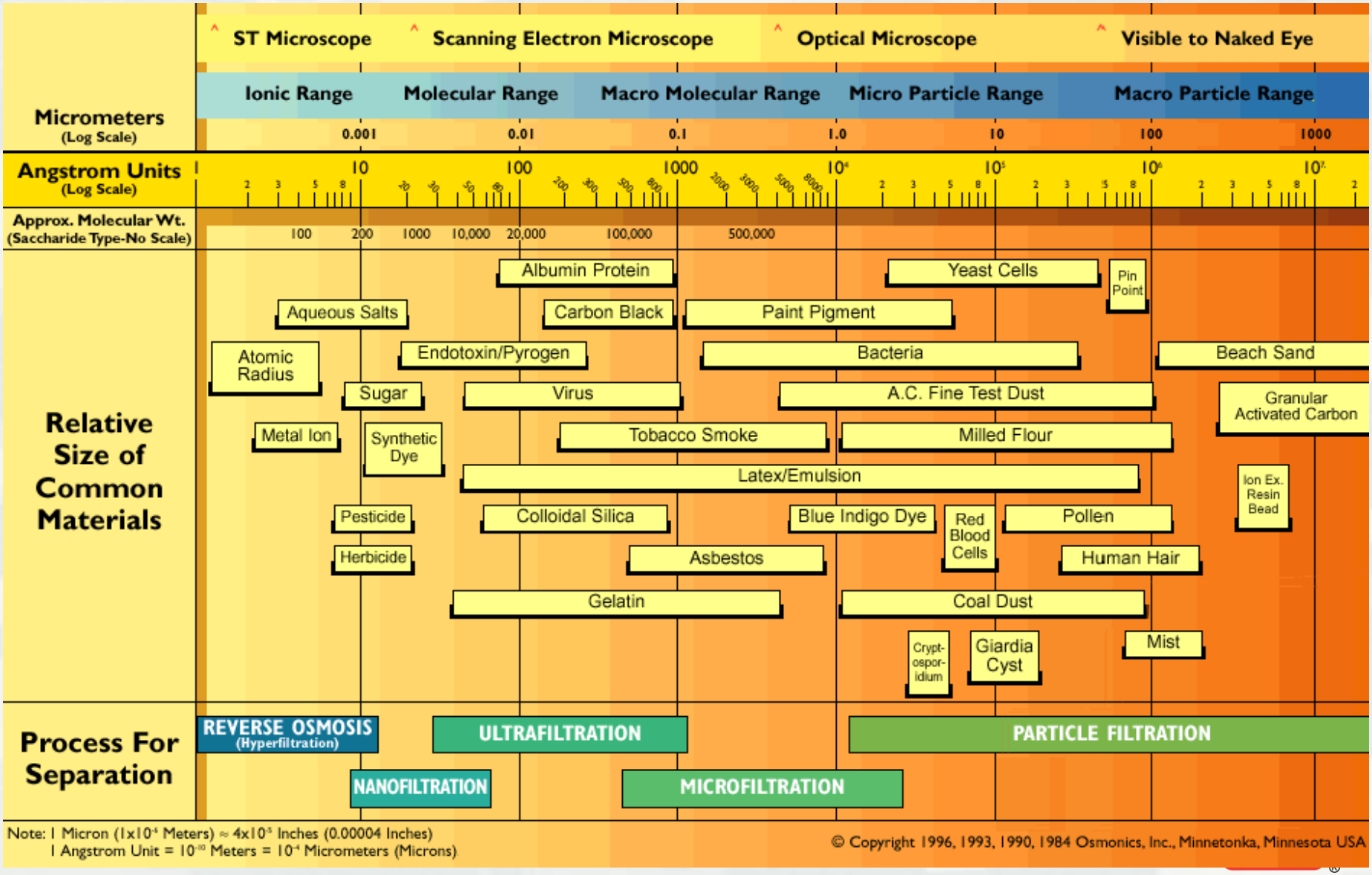
- Any interaction between the contaminant and the pipe wall will prolong the the CB attack
- Surface roughness from scale or corrosion slows transport and inhibits decontamination.
- Biofilm - Biological contaminants may settle in the biofilm and continue to release bio-toxins.



Summary: 5 Components of Water Security

- Water Security has 5 primary components
  - Vulnerability Assessment & Physical Security
  - Detection
    - No single sensor can determine the contaminant type and amount released into the system.
  - Modeling - better models of contaminant fate & transport are required to:
    - Preplan response to attack
    - Monitor the progress of an actual attack
  - Countermeasures -
    - Water treatment
    - Pipe Decontamination - 5% of the attack can cause 95% of the cleanup cost
  - *ULTIMATE GOAL: Emergency Response*
    - *Coordination of these resources*

Countermeasure - Filtration Methods

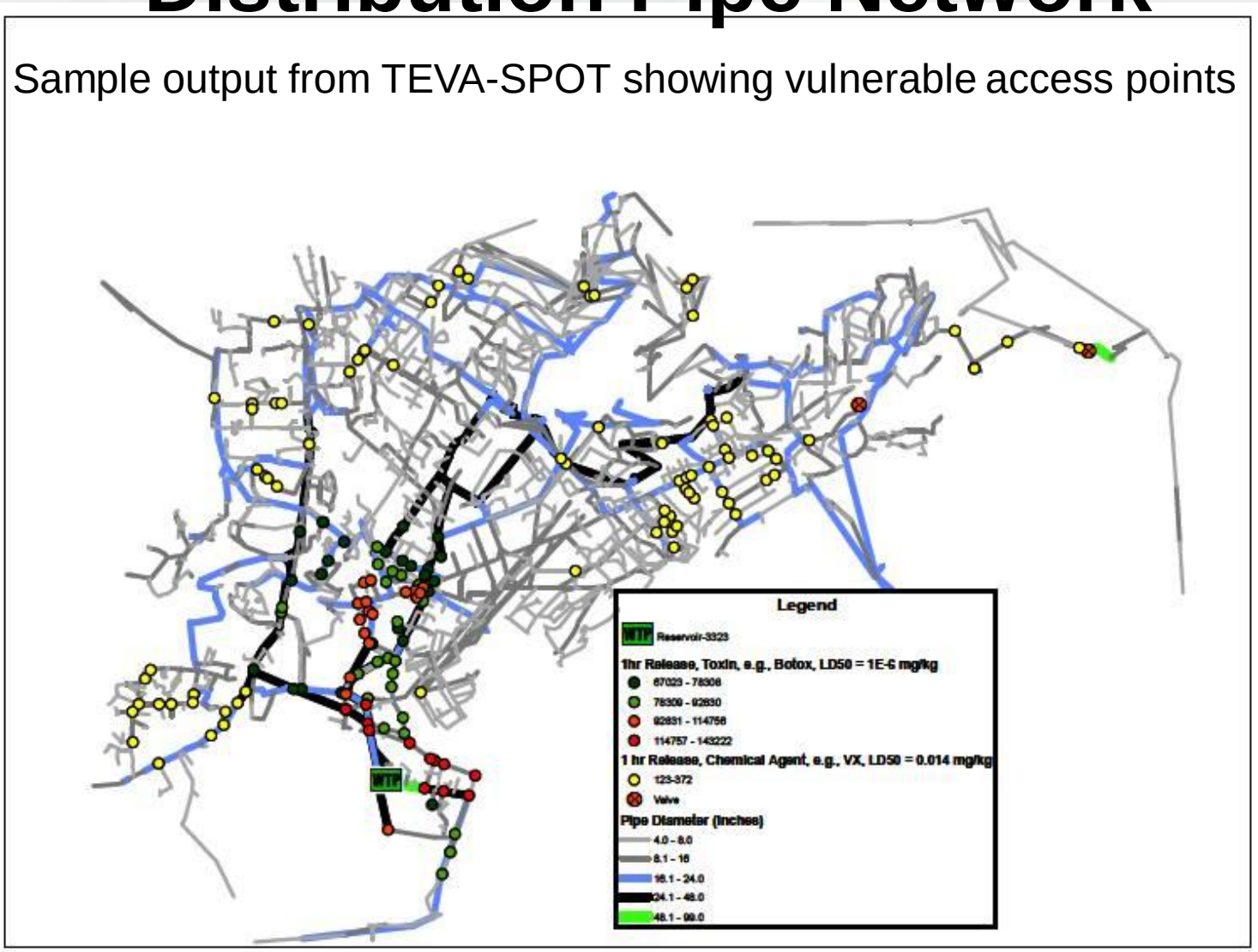


A Cautionary Tale:

- 1980 Purposeful injection of chlordane into distribution system at an isolated valve location
- System served 10,500, of which 154 reported ill effects
- Continued contamination evident following initial purging resulted in mandated use restrictions
- Ultimately resolved by extended flushing (concentrations reduced from ~1000ug/l to 0.3ug/l target over 3 months)
- Flushing able to restore usage in 1 month, but 9 months required for potable clearance
- Water heaters particularly difficult to clean

Vulnerability Assessment of the Water Distribution Pipe Network

Sample output from TEVA-SPOT showing vulnerable access points



Sensor Monitoring via SCADA

- Utilized army installation's existing Bristol Babcock SCADA system
- Corrosion rate and water quality sensors are monitored
- Data transmitted to Public Works office